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Design of Electronic Experiments
Using Computer Generated Virtual Instruments

by

Theodore Joseph Serbinski
Lieutenant, United States Navy
B.S., University of Idaho, 1983

Submitted in partial fulfillment
of the requirements for the degree of

MASTER OF SCIENCE IN ELECTRICAL ENGINEERING

from the

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Specifically, this thesis reports on the practicality of using a standard personal computer equipped with National Instruments LabVIEW for Windows and a data acquisition board to replace the typical manual instrumentation and data extraction required for seven Naval Postgraduate School ECE 2200 laboratory experiments. Appendices include the front panel display with associated block diagram code and the revised course laboratory experiments.

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ABSTRACT

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Specifically, this thesis reports on the practicality of using a standard personal computer equipped with National Instruments LabVIEW for Windows and a data acquisition board to replace the typical manual instrumentation and data extraction required for seven Naval Postgraduate School ECE 2200 laboratory experiments. Appendices include the front panel display with associated block diagram code and the revised course laboratory experiments.

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I. INTRODUCTION

A. BACKGROUND

Since the very first instrument was created their purpose and performance has evolved by utilizing the general-purpose technology of that period of time. As the personal computer (PC) continues to modify the present way in which we all live, instrument design and use is attaining even newer levels of efficiency and increasing flexibility. By combining PCs with traditional or new-generation instrument hardware, even higher levels of performance can be obtained and eliminate a test bench full of instruments. It appears that the benchtop instrument now faces the same fate as the now limited use drafting boards and typewriters.

The traditional benchtop stand-alone box instrument is a critical tool used for developing much of today's technology and is enjoying a relatively long electronic lifespan. These instruments perform a specific measurement task, operate independently, and usually combine several functionalities in one physical structure manufactured by a single vendor. These functional areas are classified into - data acquisition, analysis, and presentation. Measurement information is forwarded to the data acquisition section of the instrument usually through a hookup of test leads. The system then analyzes the data, that is, a means for retrieving information from acquired signals or stored data. Finally, the system presents an output to the viewer as a scope display, meter movement, or readout. The output presentation is defined by the vendor using generic display features.

If you strengthen the limited capabilities of a traditional instrument with user-defined enhancements of a computer, you have a Virtual Instrument - the user, not the vendor, specifies the ultimate utilization and display preference.

Data Acquisition for education has evolved also since the PC is now common in most laboratories. It has not been that long ago that financial planners with little technical knowledge were generating complex spreadsheets on PCs, while engineers were struggling for days to obtain simple measurements. Although the PC is now in use with lab work, many researchers, engineers, and students have not realized the full potential of their computers as a laboratory tool. Basic test and measurement functions to determine pressure, temperature, force, and electronic signals can be obtained by using an inexpensive PC with an installed data acquisition board, and appropriate analysis software to run the system. Data analysis is simplified, and processing of results can be specialized to specific requirements of the user. With these PC-based systems, benchtop instruments can be reduced, or even eliminated. This would reduce the inventory system and help to rid an institution of highly pilferable, small instruments, and cut down on calibration requirements.

B. EXISTING SYSTEM AND SOLUTIONS

The recent availability of low-cost computer controlled data acquisition systems have made it conceptually possible to replace much of the data recording and data analysis work associated with the classical electronics laboratory experiments required in

a typical Electrical Engineering program. This thesis reports the results of a study focused on putting those concepts into practice.

Specifically, the thesis reports on the practicality of using a standard PC equipped with a National Instruments LabVIEW (Laboratory Virtual Instrument Engineering Workbench) for Windows system to replace the typical manual instrumentation and data taking required for the following seven ECE 2200 laboratory experiments:

1. Use of diodes as switching elements in clipping, clamping, voltage doubling, and gating circuit applications.

2. Measure diode i-v characteristics and plot these parameters with a curve tracer.

3. Output characteristics of a full-wave bridge rectifier constructed with four silicon diodes, observe the effect of adding a capacitor filter, varying the load resistance, and noting the result of converting the circuit into a "regulated" power supply by shunting a zener diode across the output terminals.

4. Current-voltage relations of an NPN transistor in a common-emitter circuit configuration used in both the static and dynamic operation.

5. Transistor curve tracing to examine I_C vs. V_{CE} and I_B vs. V_{BE} curves, dc gain, collector-emitter and collector-base breakdown voltage, and dc input impedance.

6. Design of a BJT common emitter amplifier to stated specifications, test it for proper biasing, signal amplification characteristics and operational stability.

7. Two-stage RC-coupled linear amplifiers with variable output-stage configurations, testing it for proper biasing in the active region and signal amplification characteristics, and verify the results with a computer simulation of a proper transistor model using the SPICE program.

The LabVIEW system consists of a special data acquisition board and Windows based application development software. The software provides the facility for generating Virtual Instruments. Several Virtual Instruments were developed and, to the degree possible, used to process digitized representations of real world analog voltage signals obtained from the data acquisition board. Programs that do appropriate analysis and output formatting for display and printing were also developed.

C. VIRTUAL INSTRUMENT HISTORY

Virtual instruments are in their third stage of development. In the first stage, traditional benchtop and research instruments used mainframe or workstation computers to simply enhance their performance. With the evolution of the PC a dramatic increase of instrument control using computers was developed. Easy-to-use software tools changed the instrument market escalating general-purpose digitizers and reducing demand for specialized benchtop instruments. By combining a digitizer with a PC, users could observe and analyze signals of interest.[Ref. 1]

By using this type of Virtual Instrument, data transfer needed to be sufficiently fast between instrument and computer. If the data transfer could not move fast enough, the specialized evaluation and presentation of signals had to reside in the traditional instrument, not the user's Virtual Instrument and provides no gain in performance. The extent of use for these Virtual Instruments is limited by the connection between PC and instrument. The user defines one functionality, while the instrument designer defines a different functionality.[Ref. 1]

To overcome this barrier the second stage of Virtual Instruments evolved. During this stage, two new approaches to instrument hardware emerged - plug-in data acquisition boards and the VXIbus (Versa Modular Eurocard Extensions for Instrumentation Bus). These opened instrument architectures allow hardware and software elements performing the acquisition, analysis and presentation, to maximize use of the PC. Direct processor bus communication, and integrated system timing, are important facets of this architecture. The new systems provided flexibility with cost-effectiveness. By using software that works with this architecture, end-users are provided easy to use instruments.[Ref. 1]

Virtual Instrument frameworks, object-oriented concepts for application-specific needs, are the current phase. This framework allows reuse of understandable code. The graphical panels developed initially can be recalled by another user and used in a new application.

This third phase of Virtual Instruments are instruments whose function and capability is determined by the software used. It is a simple graphical way to set-up and operate numerous instruments on a single computer. This allows a PC to make measurements continuously, without constant human guidance.

Virtual Instruments are self-documenting, eliminating a major headache for programmers. The block diagrams and icons are the code a programmer works with, which allows easy understanding compared to tradition lines of code.

The PC used to create a Virtual Instrument can also be used for data processing and provide unprecedented facilities for data analysis. A complete data acquisition system

using Virtual Instruments is not limited to one specific measurement task, or require independent operation.

D. THESIS ORGANIZATION

The thesis reports the results of this effort in seven chapters. Chapter II has short tutorials on electronic measurements, principles of data acquisition, the technology of analog-to-digital conversion, and the concepts of Virtual Instruments. Chapter III describes the specific data acquisition software and hardware used in this project. Chapter IV describes the Virtual Instrument design of the seven experiments discussed above. Chapter V discusses use of data acquisition systems for the United States Navy. Chapter VI contains the conclusions and recommendations of the study. Appendix A includes the front panel display and the associated block diagrams. Appendix B has the Laboratory experiment handouts to perform each Virtual Instrument Laboratory.

II. ELECTRICAL AND ELECTRONIC MEASURING

A. ELECTRICAL MEASUREMENTS

Measurement is the process by which one converts a physical parameter to meaningful numbers. Electrical measurements involve determining the quantity of electric charge, electric current or voltage present. The measuring process compares the quantity measured with an accepted standard unit defined for that particular quantity. The quantity obtained is then used to study, develop or monitor a device. The measurement obtained has to be very accurate and made with precision to derive meaningful information. Electrical measurements are obtained with deflection instruments or electronic signal processing instruments.

B. TRADITIONAL ELECTRICAL MEASURING DEVICES

Electrical measuring devices each have special characteristics that limit their use. The sensitivity, accuracy, precision, range, and design all play a vital role for determining which instrument should be used to obtain desired information from a signal. To monitor voltage, current, or impedance in electronic circuits, analog or digital instruments may be used. The selection of a type of instrument to use depends on accuracy required, ease of use, and dependability. Electrical benchtop test equipment is divided into deflection instruments, electronic instruments, and computerized measurement instruments.

1. Deflection Instruments

The deflection instrument requires a deflecting force, a controlling force, and a damping force to operate. The most common current-sensing deflection instrument uses a D'Arsonval or permanent-magnet-moving-coil movement developed by D'Arsonval in 1881. It is highly sensitive and accurate. The movement detects current by using the force produced by the interaction of a magnetic field and the current flowing through the field. This force is used to generate a mechanical displacement, which is displayed by a pointer over a calibrated scale.

The pointer deflection is directly proportional to the current flowing through the coil, provided the magnetic field is consistent throughout, the spring tension is linear and the scale is linear. Accuracy of D'Arsonval movements is about 1 percent of the full-scale reading. To measure an alternating-current of a frequency greater than a few hertz, D'Arsonval movements cannot follow the rapid variations due to inertia and damping. This high inertia gives a distorted representation for some measurements, such as a mean value per time interval.

2. Analog Electronic Instruments

Meters constructed of moving-coil movements and multiplier resistors have limitations. The resistance of these are too low for measurements in high impedance circuitry and cannot measure low voltage levels. To overcome these limitations electronic measuring devices have a high input resistance so it will not alter the voltage value being measured. The device will also amplify low voltages up to measurable levels. These devices can be analog instruments, in which the measured quantity is shown by a pointer

moving over a calibrated scale, or a digital instrument, showing the quantity as a digital display. Both must be able to measure the magnitude of a signal as it varies wi'h time.

Analog instruments perform to a specified accuracy. Accuracy of a measurement specifies the difference between a measured value and the true value of a quantity. Any deviation from the true value is the indication of how accurate the reading is. Precision, often confused with accuracy, specifies the repeatability of a set of readings, each made independently using the same instrument. In order to obtain the highest feasible accuracy, the pointer of an analog device should deflect as close to full scale as possible.[Ref. 2]

Analog meters use an amplifier connected to a D'Arsonval meter movement to measure direct-current. A rectifier is used before the amplifier if measuring alternating-current. By using a rectifier the meter will respond to the peak-to-peak value of the signal being measured. A special calibration procedure is used so the meter scale readings are in root-mean-square values.

Root-mean-square values are of greater interest when measuring pure sinewaves because it refers to the power delivering capability of the waveform. Since the ratio of peak-to-peak to root-mean-square values is 2.8:1, the actual voltage values read by the meter are divided by 2.8 to give the meter markings.

Pulses are often used as an information carrier. Pulse width or recurring frequency are then related to the measured quantity by a proportionality. Measurement is then discrete, but still analog in principle. However, if the signal being measured is

not a pure sine wave, an error will exist between the indicated and true root-mean-square values of the signal being measured.

Electronic analog meters require battery or alternating-current line power to operate. When the meter uses line power, the plug-in connector limits portability and makes them susceptible to ground-loop interference. If the meter uses battery power, the precision is affected if the batteries are not changed frequently.

3. Digital Electronic Instruments

Digital instruments indicate the quantity being measured by a numerical display rather than by a pointer and scale used in analog instruments. A digital instrument's operation is based on either the comparison principle or the converter principle. Three methods are used to obtain a measurement by either of these principles are - ramp, comparison, or integration.

The comparison principle compares the voltage to be measured with a voltage developed step-by-step within the measuring instrument. This voltage development terminates as soon as both voltages are equal. The actual number of steps is a measure of the input signal.

If the instrument uses the converter principle, the voltage to be measured is converted into a pulsed voltage whose frequency is proportional to the amplitude of the voltage being measured. The frequency is measured using an electronic counter.

Voltage-to-time conversion, or ramp, uses a linear negatively sloped ramp waveform decreasing at a known accuracy. When the value of the input signal equals the ramp voltage an electronic coincidence detector emits a pulse. This pulse opens (turns

on) a gate. When the voltage reaches zero, another coincidence pulse closes (turns off) the gate.

The duration of time the gate is open is measured by a counter that counts the number of wavelengths emitted by a very accurate, fixed-frequency oscillator. With the slope of the ramp voltage and time between gate opening and closing known, the value of the voltage applied to the input is found. Negative input voltages open the gate at zero and close it when the negative value of the ramp is coincident with the negative voltage value.

The servo-balance potentiometer, or comparison method, uses a known voltage to compare to the unknown voltage. The difference between the two values is used to create a signal that leads to the adjustment of the known voltage. This continues until both values are equal, and the value is displayed on the digital readout.

4. Errors Inherent With Instruments

Every experiment has errors introduced. Any attempt to evaluate a measurement should consider the error that could be present from the system or human involvement. System errors can only be controlled by understanding its limitations and making a proper test lead hookup. Human errors will always be present but are controllable if the person knows the importance of correct results.

Meters can introduce the following errors:

- scale error - inaccurate markings of the scale during manufacture.
- zero error - failure to adjust zero setting before making reading.
- parallax error - line of sight not perpendicular to scale.

- friction error - worn or damaged bearings causing friction of needle movement.
- temperature effects on magnets, springs, and internal resistances.
- coil-shaft misalignment on bearing.
- bent pointer or rubbing pointer.
- poor accuracy - readings taken at less than full scale usually have a larger percentage error than full scale readings.
- loading-effect due to using a nonideal instrument to measure.
- specific errors due to meter's operating principles and design.

If an unusually large error occurs it may signal that some systematic error is being committed.

5. Advantages of Electronic Signal Measurement

The advantages of using electronic signal processing include:

- making the obtained signal more sensitive to measurement.
- very low power consumption.
- high speed measurements.
- greater flexibility for remote measuring.
- higher reliability.
- higher input impedance.
- higher upper frequency limit.
- high versatility in approaching a measuring problem.

These advantages combine with the numerous possibilities of signal processing to enhance the electronic measuring process over deflection methods.

6. Analog vs Digital Instruments

Analog and digital instruments both have a place in the test measurement world. Although substantial progress has been made with analog measurement techniques, digital methods boast a faster growth. Digital instruments are easy to use, require fewer parts, and allow more rational and effective organization of the countless measurements that may be required.

Analog instruments produce a continuous range of values in both time and amplitude. Extreme care must be taken when working with analog instruments to insure the movement is not jolted out of place since the accuracy is never greater than the movement used. The accuracy of the reading is a function of several factors added together to give an overall accuracy as good as ±2%. Drift and linearity of the amplifier as well as linearity of the meter are included with the total figure.[Ref. 3]

Digital instruments are virtually insensitive to noise and drift since they use a 'high' or 'low' logic level with large tolerance intervals. The accuracy depends on the circuit used, but is generally 10 times more accurate than an analog meter. The accuracy is achieved through converting the input into digital form and then displayed as a number. This takes the guess work out of looking at a meter deflection, thus shortening the time for measurement. The value displayed may also be retained after the signal is removed. A digital instrument is ideally suited for routine measurements by non-technical personnel.[Ref. 4]

C. COMPUTERIZED MEASUREMENTS

Advances with electronics have led to a variety of computer based instruments. Flexibility has been added to traditional measurement tools since computers help introduce devices not previously feasible. Keyboards replace switches, real-time graphics are common, software analyzes results, and data is easily stored for future reference. With relatively minor changes in software or hardware, a system's capabilities can be easily altered.

Traditional benchtop instruments play an important part of electronic development. But most benchtop instruments are specifically designed and committed to one function. Performance of the instrument is guaranteed to be within stated specifications, but the instrument is not flexible in measuring a multitude of parameters.

Virtual Instruments, as used in a Data Acquisition System, are designed with a philosophy of using basic building blocks - Analog-to-Digital converters, analysis software, and digital signal processors. This combination installed in a PC can actually perform the functions of one or more laboratory instruments, which then provides a comprehensive flexibility to tailor a Virtual Instrument to perform exactly as needed by an operation.

Test-and-measurement applications using state-of-the-art instruments currently use a standard PC having one or more expansion slots, a high-performance Analog-to-Digital and Digital-to-Analog plug-in data acquisition board, and acquisition and analysis software. By placing these components within a PC, it is transformed into a high speed precision Data Acquisition System. A typical PC-based data acquisition and control

system will allow the user to measure physical variables, input the acquired data to the PC, analyze the data using software, and provide appropriate response to control the process.

A simple example of a PC controlled device can be illustrated using the temperature regulation in a house. A thermocouple is used to continuously measure room temperature. This thermocouple signal is then converted from analog to digital format readable by the PC utilizing an acquisition board. Acquisition software is used to compare the desired temperature with the thermocouple signal which then causes the PC to respond via a digital output able to adjust the heating or cooling circuit.

D. A DATA ACQUISITION AND CONTROL SYSTEM

A data acquisition system is a switched Analog-to-Digital converter that digitizes multiplexed analog inputs. Figure 2.1 shows the block diagram of a basic data acquisition system.

1. Sensing and Signal Conditioning

If a physical variable such as length, pressure, fluid flow, or motion is an input, a transducer is used to sense and measure. This transducer converts the physical variable into electrical signals, voltage or current, and transmits them to a signal conditioning device or directly to the data acquisition board. A signal conditioning device amplifies and filters a real-world signal for use by the analog input board.

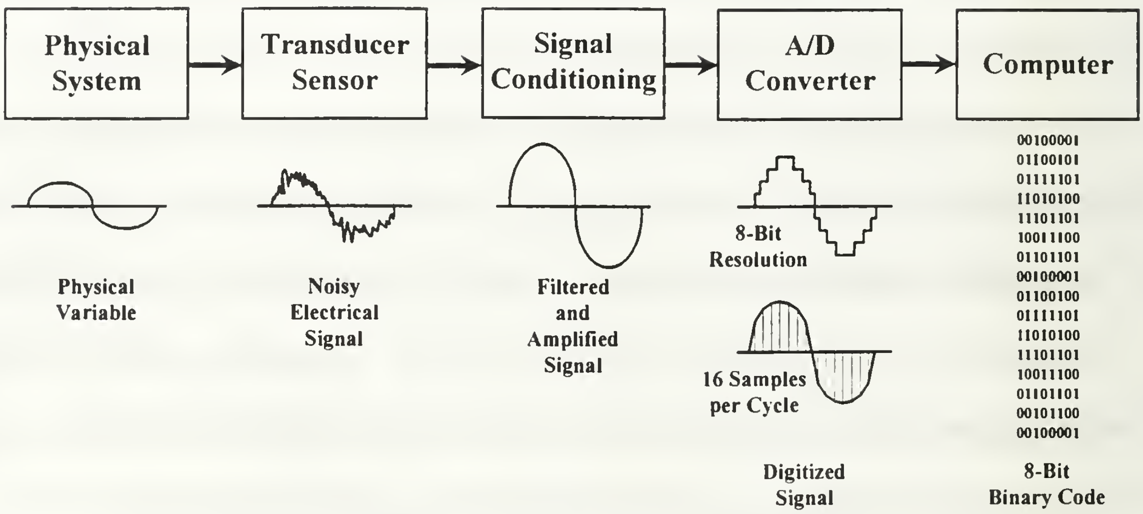


Figure 2.1 Basic Data Acquisition System Block Diagram

When PC-based data acquisition boards were first used in a laboratory, technicians assumed they could plug the board into a computer slot, clip on a few test leads between board and test device, and immediately take measurements. They found that actual valid measurements do not conform directly to the data acquisition board's input sensitivity. It was also seen that quality signal conditioning can make a difference between expected data and useless numbers.

Signal conditioning modules serve to isolate test signals from electrical noise and provide overvoltage protection for the data acquisition boards and PC. The modules have the ability to read very small voltages while rejecting large amounts of noise from the surrounding environment. The modules also help to isolate the PC from transient

voltages picked up by the test leads. These transient voltages could be high enough to destroy the computer or the data acquisition board. High-frequency transients that could corrupt the signal can be eliminated by use of a low-pass filter built into the signal conditioning module.

2. Data Acquisition Boards

Following signal conditioning, the sensor signal is passed to the Analog-to-Digital input section on the data acquisition board. This section converts the voltage or current signal into a digital format readable by the PC. The Analog-to-Digital section has the capability for high-speed Direct Memory Access data transfer to the PC, first-in-first-out memory buffering, noise and filtering of false lower frequency components (alias frequency).

An analog signal is a time-varying quantity with the amplitude exhibiting a continuous variation over the range of activity. This signal must be converted into a discrete time signal, a digital signal, in order for the computer to represent the original signal.[Ref. 5] Analog-to-Digital conversion is a ratio operation, where the input signal is compared to a reference (full scale input voltage), and converted into a fraction, which is then represented as a coded digital number. To optimize measurement accuracy, there is a minimum and a maximum number of data points that need to be acquired. Analog outputs for data acquisition boards are generated in the exact reciprocal of that to read the inputs.

Sampling rate is important for data acquisition boards. The Analog-to-Digital sampling rate is a measure of how fast the board can scan an input channel and compare

the discrete value of the signal present with respect to a reference value. Selecting a slow sampling rate can construct a completely different waveform of a lower frequency, or aliasing, from the acquired data. A data acquisition board sample rate that is bandlimited and samples at least twice the expected input frequency, the Nyquist sample rate, can avoid aliasing. For example, to sample a 1 Hz sine wave, the sample rate should be at least 2 Hz, but a sample rate of 8 - 16 Hz results in a more accurate representation of the acquired signal. Figure 2.2 shows several sampling rates of an analog waveform.

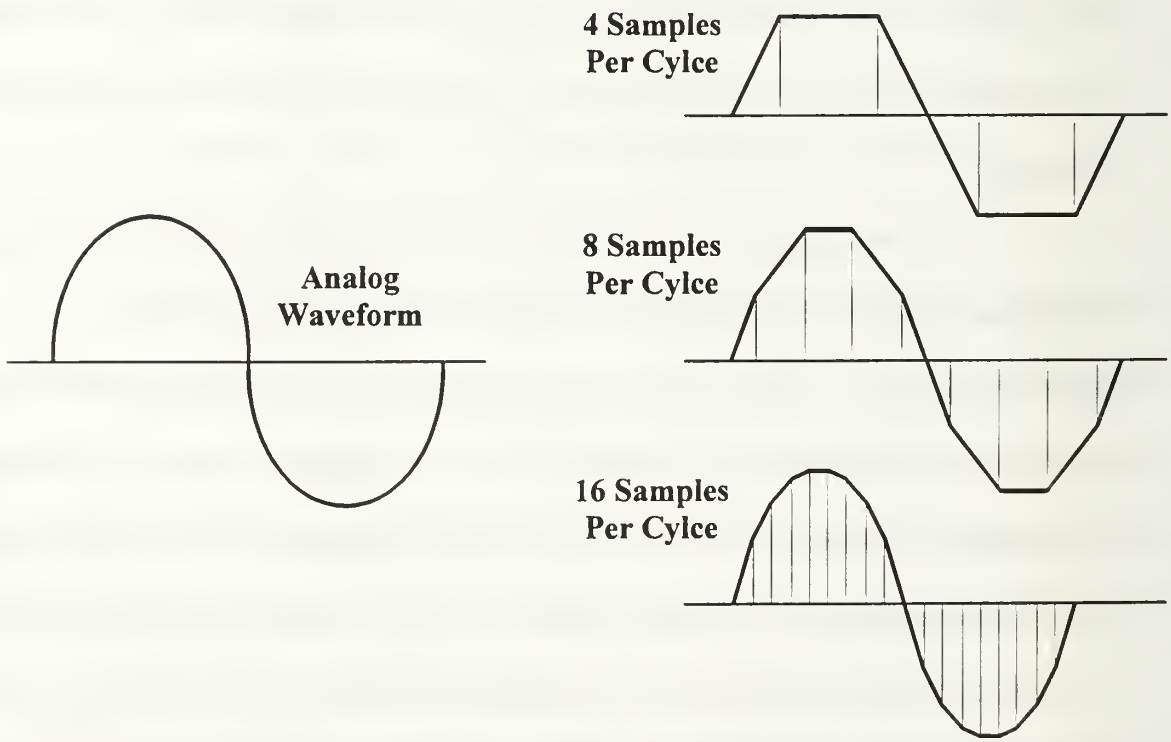


Figure 2.2 - Different Sample Rates

Throughput rate is the maximum frequency at which a data conversion process will operate within a specified accuracy. If a data acquisition board selected has 8 input channels, a maximum throughput rate of 8 Hz, and samples are taken on a only one channel, the system will acquire 8 samples per second for that channel, an 8 Hertz sampling rate. If the system is setup to test all 8 channels, only 1 sample per second is obtained giving a 1 Hertz sampling rate.

Resolution of a data acquisition board defines the number of divisions into which a full-scale input range can be divided to approximate an analog input voltage. Figure 2.3 shows various bit resolutions. To measure an input signal of 0-10 volts using an 8-bit resolution board means the signal is in steps of $10 \div 2^8 = 0.039$ volts. This breaks down to a 0 volt input equal to zero and a 10 volt input equal to the digital number 255. Since the board can only differentiate 0.039 volts or higher, if numerous signal changes of 0.035 volts occur, the system will not detect them. True resolution of data acquisition boards can be as much as 2 bits lower than specified by the manufacturer when placed into a system. Table 2.1 shows the resolution conversion for Analog-to-Digital boards. It can be seen that more bits provide exponentially higher resolution. For example, a 16-bit converter provides 16 times as many points as a 12-bit converter over the same range (see Figure 2.4), $2^{16} \div 2^{12} = 65{,}536 \div 4{,}096 = 16$.

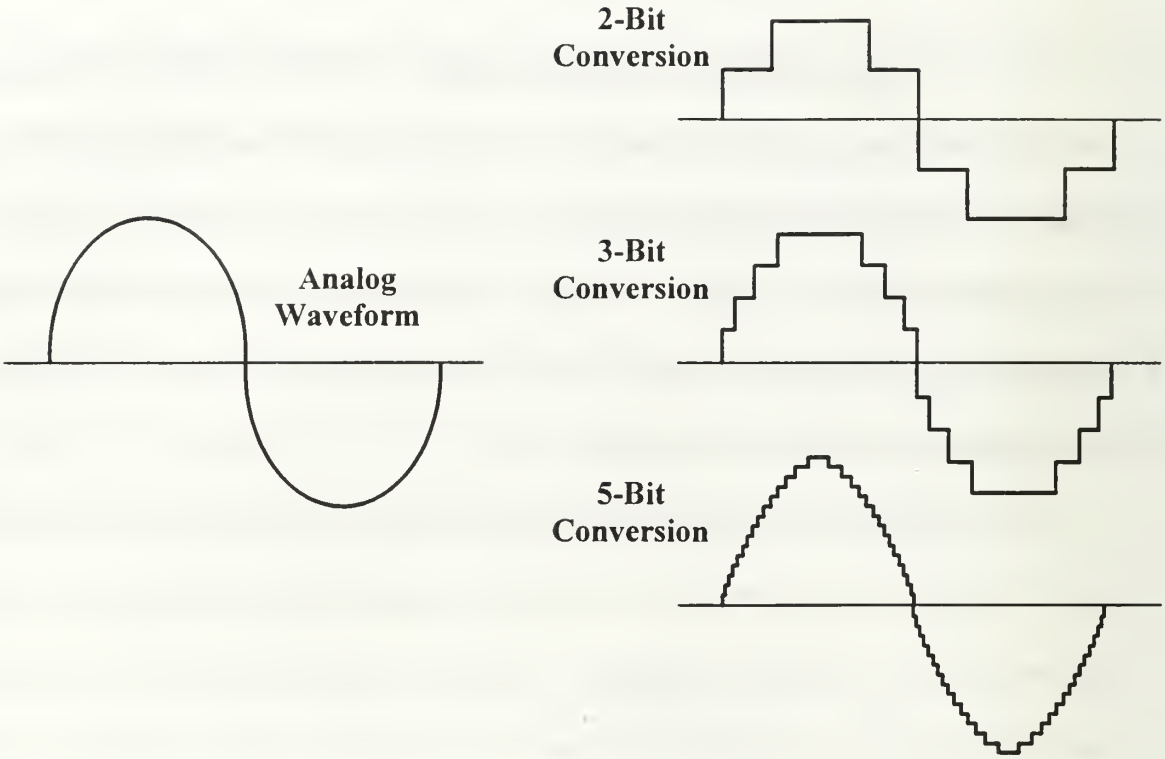


Figure 2.3 - Different Resolution

TABLE 2.1 - RESOLUTION CONVERSION CHART

Bits	2^n	% Full Scale	Least Significant Bit, 10V Full Scale
1	2	50.0%	5.0V
2	4	25.0	2.5
3	[illegible]	12.5	1.25
4	16	6.25	0.625
5	32	3.125	0.3125
8	256	0.390625	0.0390625
12	4096	0.0244140	0.0024414
16	65536	0.0015258	0.0001526

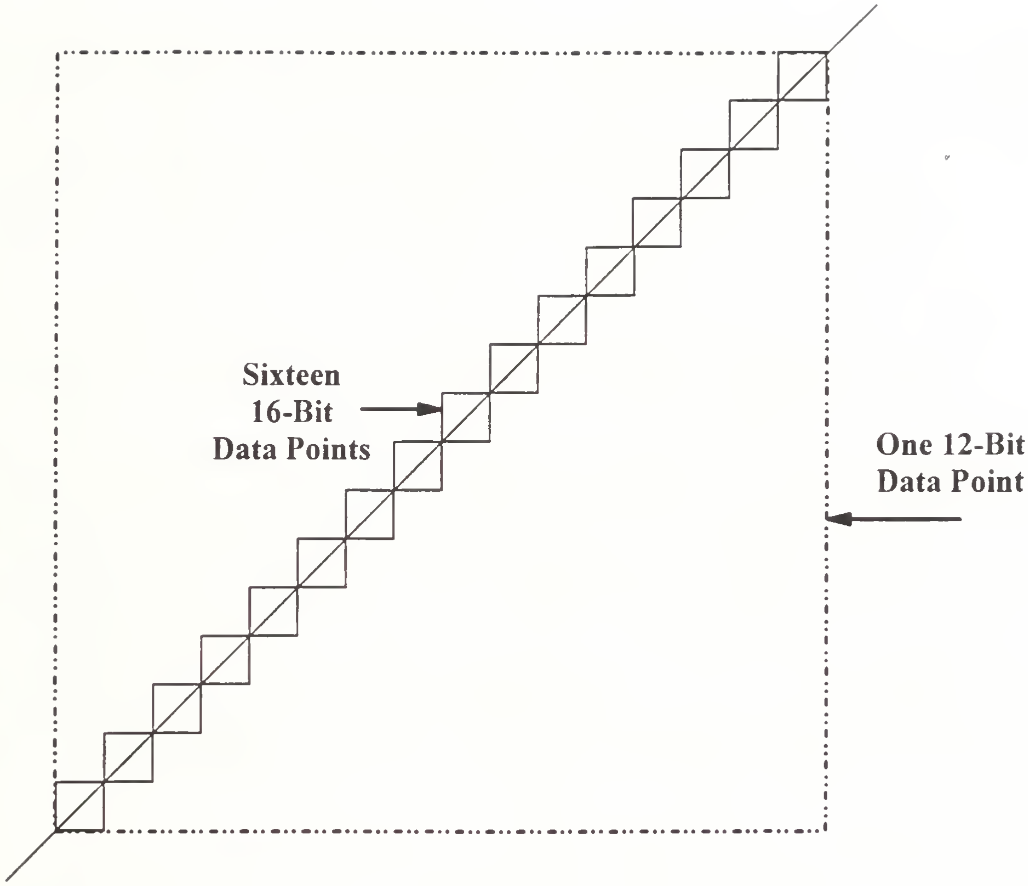


Figure 2.4 - One 16-Bit Converter Comparison

A multiplexer increases the input capability of the data acquisition board. This is accomplished by increasing the number of available input channels to as high as 256 differential or 512 single-ended. A multiplexer can be useful if the computer used for data acquisition has no available expansion slots or if there is a desire to expand an existing system.

One great advantage of using a PC with a data acquisition board is Direct Memory Access. This allows transfer of data from the Analog-to-Digital board directly into the PC's memory at high speeds without involving the central processing unit.

Analog-to-Digital boards support single-channel or dual-channel Direct Memory Access. In single-channel only a single 64K buffer is used to transfer data. That means only 64Kbytes of data is collected for each test. This data must then be transferred to the PC's memory or hard disk before performing any other measurements. Dual-channel mode is used for collecting high-speed data in a continuous mode. Here, data is transferred to the first 64Kbyte buffer, but when it is full, the Direct Memory Access switches automatically to the next buffer while simultaneously transferring the first buffer information to the PC random access memory. The Direct Memory Access switches back and forth to allow unlimited sample sizes. If very high speed data is input to the Analog-to-Digital board, a first-in-first-out buffer enhances the Direct Memory Access by storing data temporarily to avoid loss of data.

a. Sample and Hold Circuit

The sample and hold section of a data acquisition board acquires and stores signals from multiple channels of inputs for a very short instance of time. It is used to stabilize the input of the Analog-to-Digital section during conversion. Any skew between signals could lead to an incorrect portrayal of the signal generated by the device under control. Most data acquisition boards sample a channel, switch the multiplexer to the next channel, take a sample, and continue switching until all channels are sampled. One can see there is a time delay between the first sample and all following samples taken. A typical board with 16 channels and a 10μsec sample time has a 160μsec time skew between first and last samples. To avoid timing errors, boards use simultaneous sampling. Data is sampled on all channels at exactly the same time and is then held in

a 1-sample per channel buffer until the Analog-to-Digital section can scan the data. Figure 2.5 shows conventional and simultaneous sample and hold circuits.

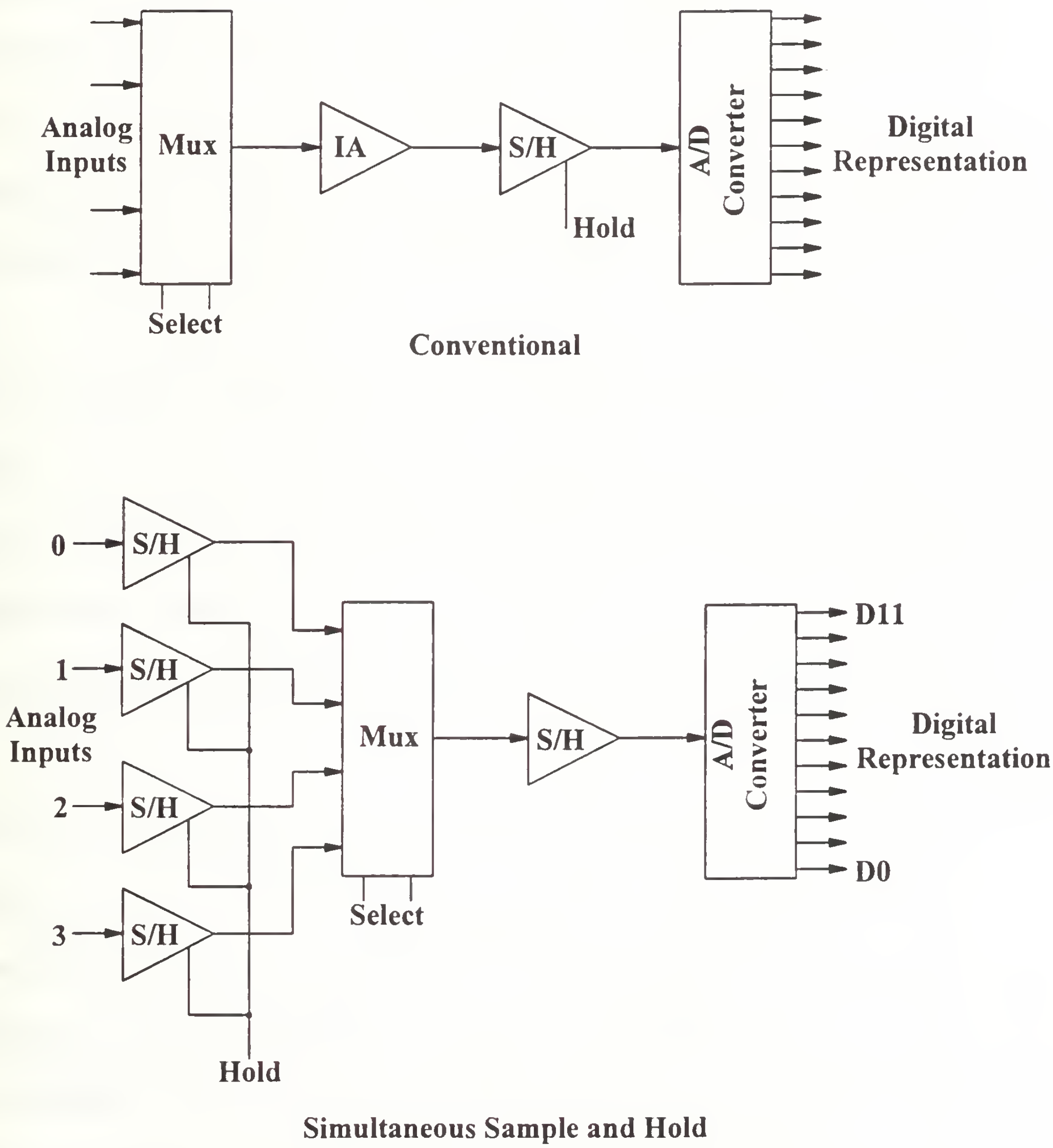


Figure 2.5 - Sample and Hold Circuits

b. Input Configurations

Connecting a data acquisition board to a circuit is not the same as hooking up a multimeter with two tests leads. A data acquisition board is very sensitive compared to a multimeter but recognizes small noise fluctuations as a true signal. To help eliminate noise connection of the input signal to the data acquisition board is by one of three configurations: single-ended (Figure 2.6), differential (Figure 2.7), or pseudo-differential (Figure 2.8). Single-ended inputs are cost effective, true-differential offers greater noise immunity, and pseudo-differential is a practical solution to most cable-induced noise.

Single-ended inputs should be used when analog measurements are made with respect to one common external ground, and there is no practical way to bring both a remote ground and the analog ground back to the Data Acquisition System. Criteria for single-ended connection are: high-level input signals (greater than 1 volt), leads connecting signals are fairly short (less than 15 feet), and all inputs share a common source reference signal.[Ref. 6]

True-differential should be used when each input signal has its own reference signal or signal return path. This configuration usually means the data acquisition board's number of available channels is half the maximum since each input signal is tied to a positive and a negative connection point of the instrumentation amplifier. Criteria for use are: low level input signals (less than 1 volt), input sensor is physically removed from the Data Acquisition System (leads greater than 15 feet), and when a sensor being measured requires a separate ground.[Ref. 6]

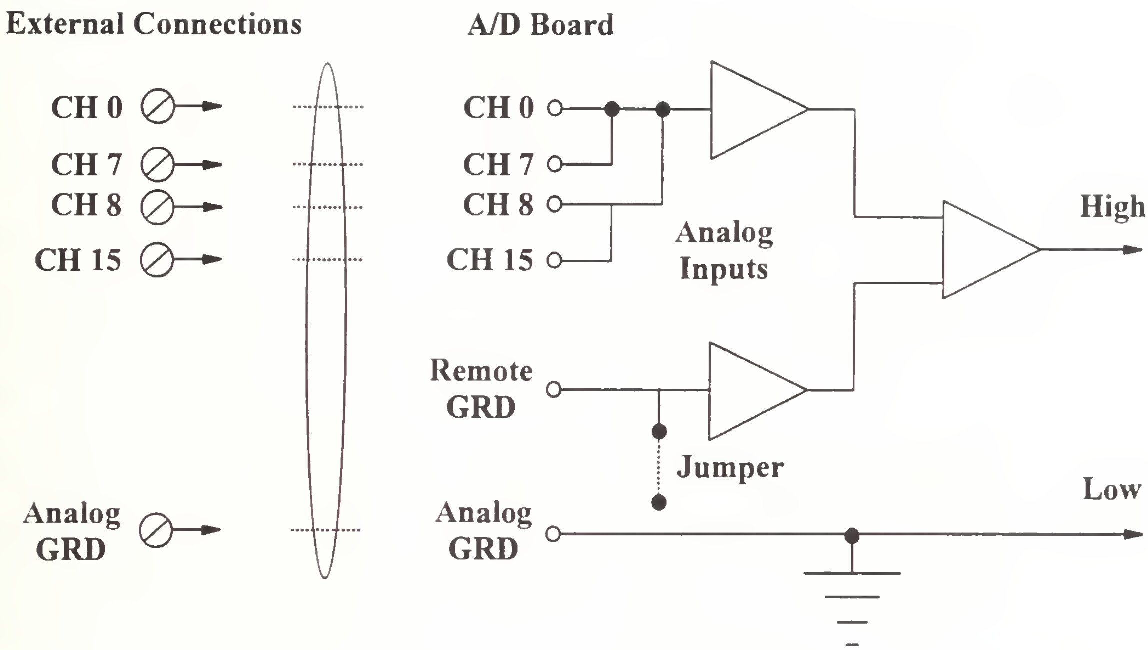


Figure 2.6 - Single-Ended Inputs

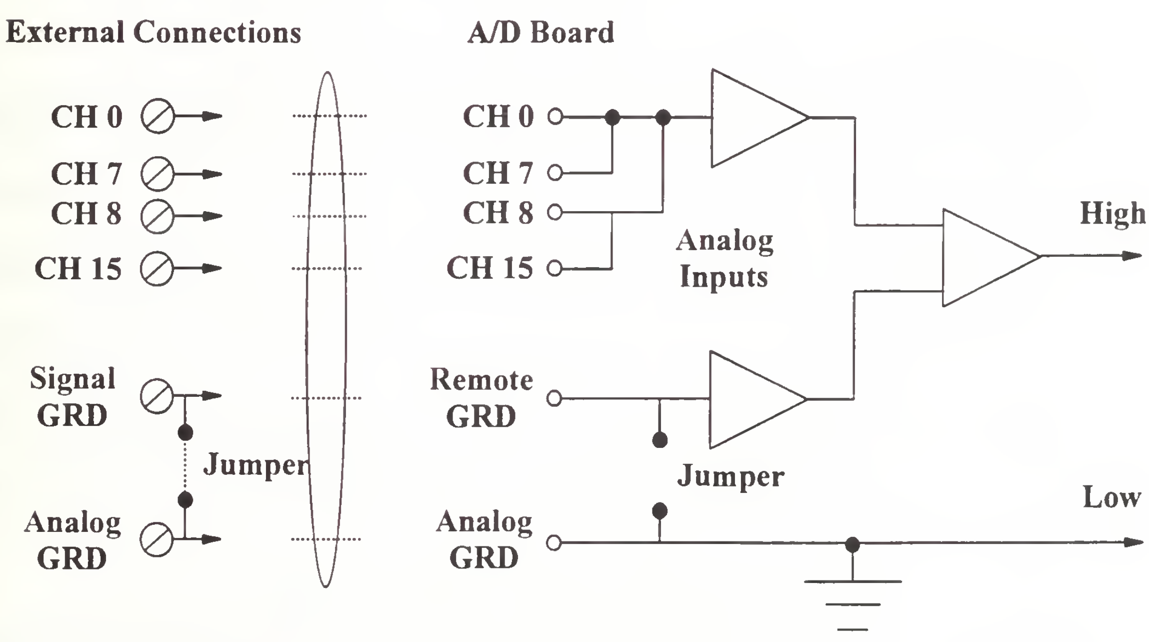


Figure 2.7 - Pseudo-Differential Inputs

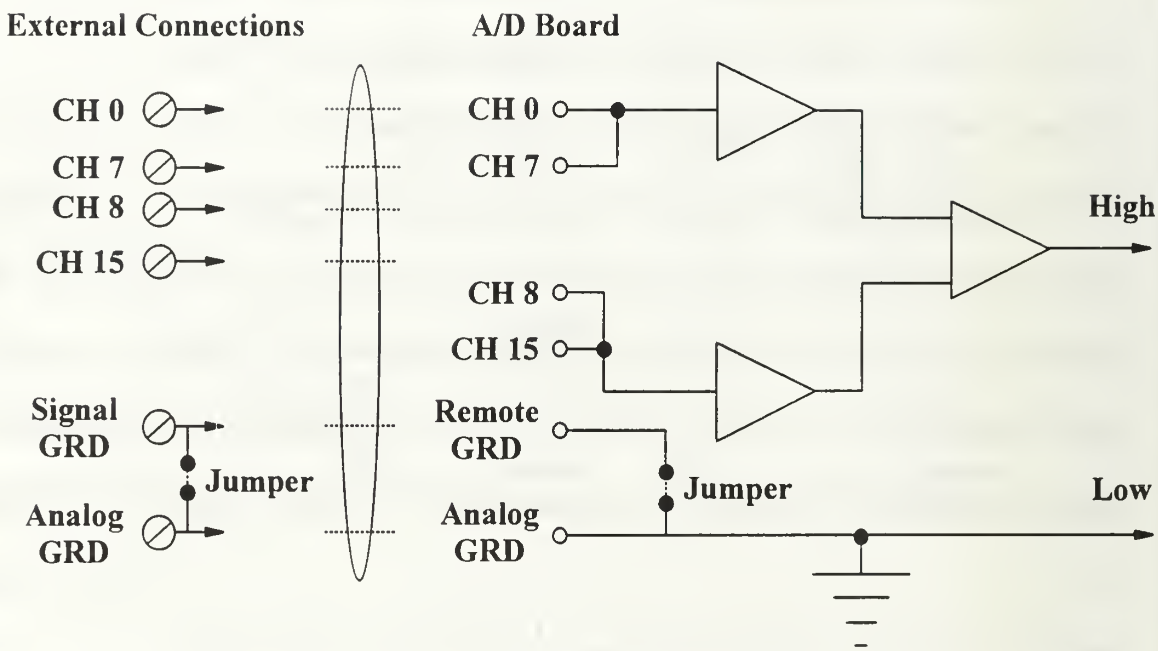


Figure 2.8 - True Differential Inputs

Pseudo-differential applies mainly to a configuration with leads going through very noisy environments. Using this configuration references the signal source to the system ground. A pseudo-differential connection is made when common lines of all channels are tied to the signal ground. This rejects (common mode rejection) the noise induced into the cable. Differential connections can help reduce pick-up noise and increase common mode signal and noise rejection.[Ref. 6]

c. *Self-Calibration of Data Acquisition Boards*

Equipment calibration is required periodically for all test equipment since it is being used to compare signals or values to an internal known standard. Calibration

of some data acquisition boards is accomplished using internal factory-set standards. The analog inputs and outputs of the board have self-calibration circuitry to correct for gain and offset errors. It is also possible to calibrate out additional analog input or output errors of time and temperature drift during run time. Environmental changes of this type are usually accomplished through software. That means no external circuitry is required. Internal references are used to ensure high accuracy and stability over time and temperature. Factory calibration constants are permanently stored in an onboard EEPROM (electronically erasable and programmable read-only memory) which is not modifiable. Some data acquisition boards allow a section of the EEPROM to store user-modifiable constants. These user constants can also be restored to the original factory settings if required.

3. Typical Data Acquisition Computer System

The typical benchtop digitizing instrument may consist of front-end and sampling circuitry, memory, front-panel user interface, CRT (cathode ray tube) screen and an IEEE 488 interface (a General Purpose Interface Bus, GPIB, used for controlling electronic instruments with a computer). With the exception of the front-end and sampling circuitry, a user can obtain more functional versions of the same components via a PC equipped with data acquisition and analysis software. The software duplicates the instruments display, front panel and data handling capabilities.

The heart of a Data Acquisition System is the computer. It is used to house the data acquisition board, software, and also display the data. The rugged industrial PC is growing in popularity and will add to the application of data acquisition. The decrease

in PC prices with an increase in application power allow the PC to integrate, or surpass, the built-in functionality of benchtop instruments.

A monitor as the display screen plays a vital role for Data Acquisition System integration with the user. They are used to observe vital gauges or simple one output graphs to multiple signals compared on one multi-plot grid graph. System inputs and outputs can be viewed on the monitor to insure proper response.

4. Software

Data acquisition software has the ability to obtain and analyze data and produce a hard copy of test results. Procedures can be repeated with consistent results. This gives data acquisition software a tremendous advantage over human data recording. Data acquisition software makes it possible to automate most of a test process, reduce risk of operator error, and guarantee that measurements will be performed consistently. By using software, automated analysis and data collection modifications to perform a different testing procedure is easy. One Virtual Instrument can be applied to a variety of others with little or no modification.

Development of Virtual Instruments are generally performed using graphical user interfaces. The software provides complete flexibility for tailoring the Data Acquisition System to suit exactly what is required from a user. It is also versatile enough to accommodate various instruments and data acquisition devices that will be used in the system.

The software is critical to the reliability and high-performance operation of the Data Acquisition System. Virtual Instrument software provides an integrated tool for

acquisition, analysis, and presentation to the user. Data logging to a disk, displaying real-time control data, and online performance of data analysis is simplified into one system. Most manufacturers have instrumentation driver libraries to operate their instruments which aid in development of user specific applications.

Data analysis functions are used to remove noise perturbations, correct for data corrupted by slightly defective equipment, and compensate for environmental effects of temperature and humidity. The software can then use the acquired information to perform the following functions: signal generation, signal processing, digital filtering, numerical analysis, statistical analysis, and regression analysis. By combining any one or all of these functions, a user can develop custom algorithms specific to one research or educational application.

Designing a specialized application is modular and starts by selecting the desired function blocks from a program library to build a software model. The libraries contain analog input/output, digital input/output, counting, data flow, comparison, frequency, digital signal processing, signal measurement and analysis, user interface and display, and file input/output. By connecting these blocks together, a user can create a control structure with parameters peculiar to the application. By showing voltage data on one axis of a graph and time on the other, the Virtual Instrument appears to be an oscilloscope, for example. Or it could analyze an array of data using a Fourier transform, and present spectral information, amplitude as a function of frequency, as a spectrum analyzer does. Unlimited run-time systems controlled by the same PC can be created with just one copy of the software. The Virtual Instrument created usually is modular and

hierarchical, allowing a Virtual Instrument to be a sub-Virtual Instrument within a Virtual Instrument.

The interactive user interface, or front panel, imitates the panel of physical instruments. This panel contains the knobs, buttons, graphs, and indicators to control and display the signal. Panel data input is controlled by a mouse and keyboard. The user can change any job function at will to suit a wide range of applications. The flexibility of the software is the greatest asset to the Data Acquisition System for future expansion. New hardware may be purchased, but the software and the Virtual Instruments developed remain the same.

5. Advantages of a Computerized Measurement System

Changing from a manual to an automated measurement system, a user obtains many benefits including the following:

- simplification of test lead hook-up.
- faster measurement speed.
- more accurate results.
- reduced random errors from operator fatigue.
- reduced manual handling of data.
- more interaction with theoretical calculations since the measured data is used directly as an input.
- Turnaround time between measurement and final output of data is faster.
- greater ability to process, transfer, or store data.

A Virtual Instrument is not the answer for every measurement application. Some applications may only be required to be performed once a year, for which a Virtual Instrument design may not be practical due to time of development. In general, although initial set-up for a Virtual Instrument can be difficult, once the design has been completed, measurements are faster and easier. They also allow an experiment or measurement to be repeated many times using consistent measuring and control techniques.

III. DATA ACQUISITION USED IN A STUDENT LABORATORY

A. CURRENT LABORATORY SETUP USING TRADITIONAL BENCHTOP INSTRUMENTS

Naval Postgraduate School's Electrical and Computer Engineering Electrical Engineering course laboratory was designed for a student to perform tests using a variety of test equipment, (Figure 3-1). Each piece is specialized for one purpose, such as power supplies, function generators, frequency generators, and oscilloscopes. During a student laboratory session, each piece of equipment must be found, plugged in, turned on, and output adjusted correctly for each experiment. For every experiment performed, wires must connect each piece of test equipment to the circuit. The current arrangement requires that a student and instructor spend laboratory time setting up just to get to the point of starting an experiment. Performing the experiment also requires several changes to the test equipment configuration used. The objection of the laboratory is to study characteristics of electronic devices, not how to master a piece of test equipment.

The test equipment components used by each student requires a substantial amount of test bench space. In addition, the large assortment of test equipment requires a number of electrical sockets for power cords, further increasing confusion when moving equipment.

While performing the experiment, the student must observe the circuits output, answer applicable questions, and sometimes compare results with a manufacturer data

sheet. Additionally, during various portions of the experiment the student must sketch the input and output voltages versus time, noting the test equipment settings.

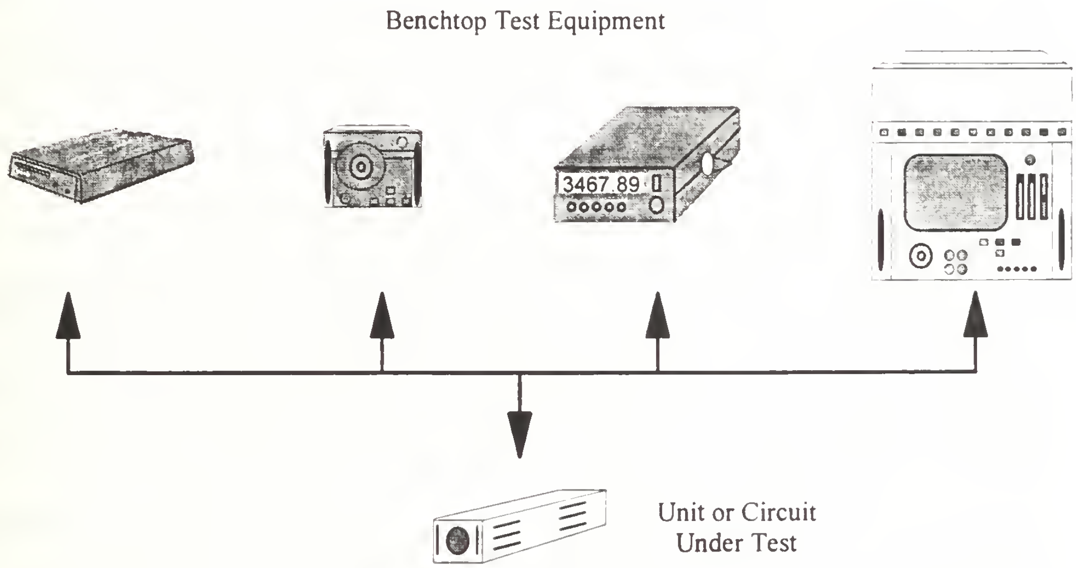


Figure 3-1 - Current Electrical Engineering Lab Setup

B. LABORATORY SETUP USING VIRTUAL INSTRUMENTS

Implementation of an electronics lab using Virtual Instruments can simplify the way students and instructors perform experiments. The major obstacles of the present lab, (i.e. finding equipment, hooking it up, adjusting output, and time spent drawing), are overcome by using a PC, data acquisition board, and compatible analysis software. Ease of use and control through software increase the professor's electronic device instruction and the

student's hands on test time. When using Virtual Instruments, more test circuits can be constructed by the student and verified during the laboratory.

The data acquisition laboratory setup utilizes an IBM compatible 80486DX 33MHz computer, Super Video Graphics Adapter monitor, National Instruments AT-MIO-16F-5 Data Acquisition board and associated software, and LabVIEW for Windows program development application software. The system runs under Windows with DOS 5.0. No other software is required except for the video monitor drivers.

The lack of some student's knowledge of computers requires periodic maintenance of hard drives to determine if unwanted files exist. Corruption of hard drives with added software through misuse of students necessitates having a quick system to renew each hard drive at the end of a new academic quarter. To allow software maintenance, the data acquisition laboratory has a backup system consisting of a Bernoulli Universal Transportable Multidisk 150 and storage disks. This unit allows the school to maintain a master and backup copy of all Virtual Instruments on two 150 megabyte removable disks and be kept in a secure place. Any future changes to a Virtual Instrument can be loaded on the master and backup disk, and then transferred to each PC. Hard drive failures, such as computer viruses, resulting in complete re-formatting will be easier to recover from if all the lab data is contained on one master disk.

The PCs have password protection via software and can only run a Virtual Instrument, not modify the Virtual Instrument function. The entire laboratory experiment section of the course is placed in a class directory with individual Virtual Instruments corresponding to each experiment. The experiment write-up is also contained in the

directory for print out in case the student forgets their instruction sheet. Due to the simple requirements of this lab, no floppy disk file saving function for the student was implemented. All Virtual Instrument labs can be performed during the allotted time period to eliminate saving of data.

The ten computer data acquisition laboratory setups are connected to one Hewlett Packard LaserJet 4 printer by an automatic switching circuit for independent student experiment output. Using a LaserJet printer simplifies the instructors grading since all experiment results will be standardized. Analysis of waveforms is also easier for the student when viewing a computer generated hard copy output.

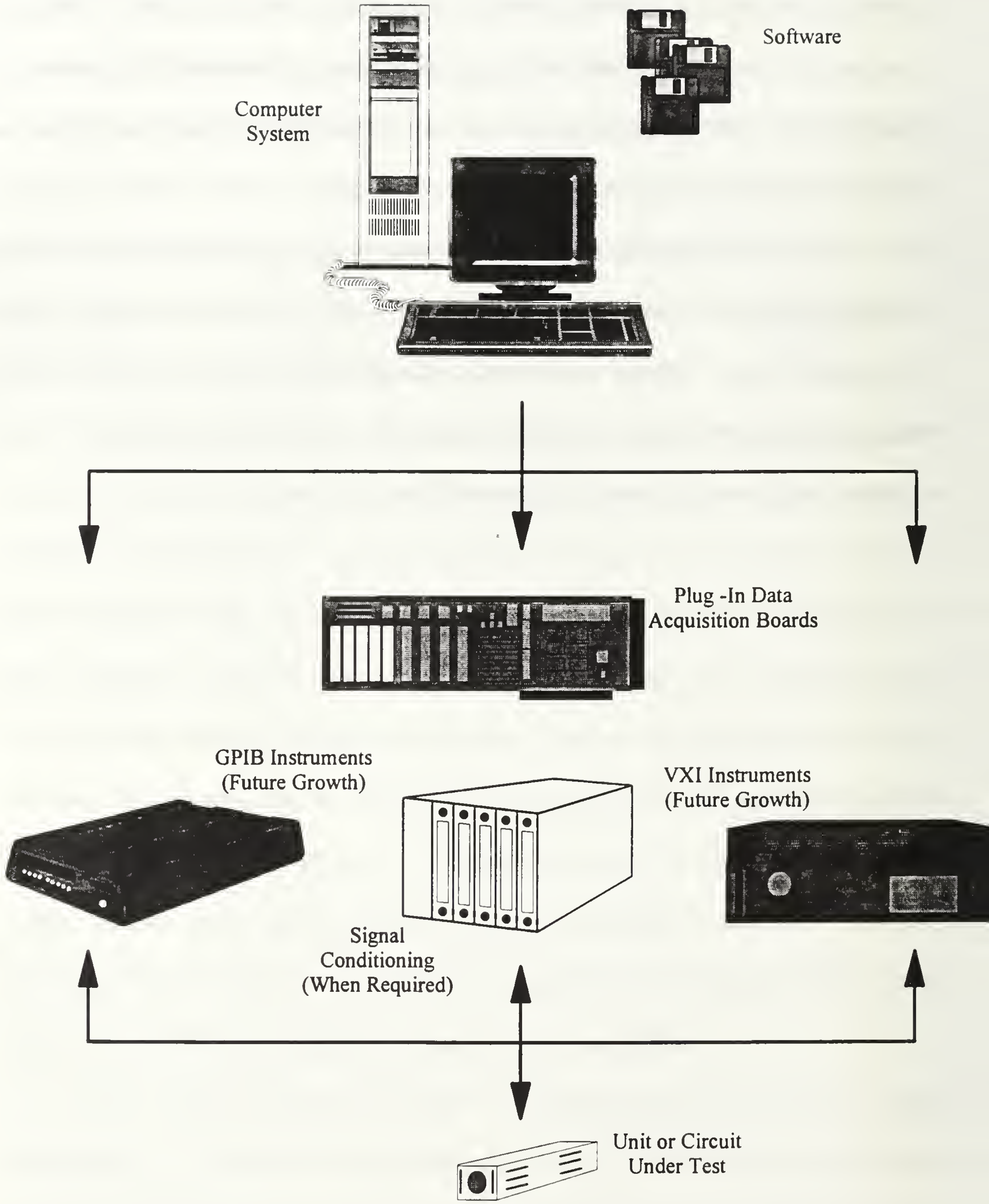


Figure 3-2 - Data Acquisition Laboratory Setup

1. Data Acquisition Component Specifications

The ten PCs used for the laboratory utilize the VESA local bus, have 120 megabyte hard drives, 8 megabytes of RAM, 3½" and 5¼" high density floppy drives, and Super Video Graphics Adapter video cards. The PCs are housed in a medium tower case to allow for the data acquisition board with external cable connection and future expansion. Each PC has a 14" non-interlaced Super Video Graphics Adapter color monitor, a mouse, and keyboard connected.

The Typhoon video graphics card has 1 megabyte of display memory and supports a resolution range from 640 × 480, 60 Hertz and 16.8 million colors to 1280 × 1024, 43.5 Hertz and 16 colors. Resolution is software selectable with the 800 × 600, 60 Hertz and 256 color setting selected for use in the lab to maximize the information presented on the small 14" screen from the Virtual Instrument of the experiment. This setting is also used to allow sufficient character size for students to read displays.

The following is a list of the data acquisition board's major specifications:

- ±5 volt or 0 to +10 volt differential analog input range which is software selectable
- 15 volt power-off and ±25 volt power-on overvoltage protection
- programmable gains of 0.5, 1, 2, 5, 10, 20, 50, and 100
- software controlled self-calibration
- 256-sample First-In-First-Out Analog-to-Digital Controller buffer
- 200 Kilosamples/sec sustained sampling rate
- 16 single-ended or 8 differential channels

Virtual Instrument design to support each experiment was limited to the data acquisition board's specifications. Two lab experiments could not be construrted as Virtual Instruments, the PN Junction characteristics of diodes and the curve tracing experiment with transistors. This was due to the high voltage (200+ volts) required to place the devices in the break-down region for testing to check manufacturer's data sheet characteristics. The National Instrument's board used has an output limit of 10 volts, much lower than that required to bring a 1N483B Silicon Diode or 2N3405 NPN transistor into the breakdown region. Safety considerations were a main factor in not implementing curve tracing utilizing an external power source to drive the devices into breakdown. Another limit was found when one experiment required two direct-current voltages in addition to a sinewave. The board has the ability to output a maximum of two different signals. Although the board has two digital output pins with a constant +5 volts, the lack of voltage control and variation to those output pins would require modification of the experiment's required output.

2. Virtual Instrument Software

The selection of LabVIEW for Windows as the primary data acquisition software was based on its demonstrated performance. LabVIEW is a program development application similar to C and BASIC. The biggest difference is that LabVIEW uses a graphical programming language, called G, to create a program in block diagram form. The other applications use text-based languages to create lines of code.[Ref. 7]

LabVIEW is a general-purpose programming system with extensive libraries of functions and subroutines for almost any programming task. It also contains application specific libraries for data acquisition, GPIB and serial instrument control, data analysis data storage, and data presentation. LabVIEW includes conventional program development tools to set a breakpoint, animate data, and single-step through a program to ease debugging and program development.[Ref. 7]

LabVIEW calls the finished programs Virtual Instruments since their appearance and operation imitate actual instruments. The Virtual Instruments are identical to functions from conventional language programs and have an interactive user interface, a source code equivalent, and receive parameters from higher level Virtual Instruments.[Ref. 7]

The interactive user interface is called the front panel because it simulates the panel of a physical instrument having knobs, dials, meters, and graphs. The block diagram portion is a pictorial solution and source code of the programming problem constructed in G.[Ref. 7]

Using LabVIEW, a Virtual Instrument is hierarchial and modular allowing use as top-level programs, or subprograms within other applications. The icon and connector of a Virtual Instrument work similar to a graphical parameter list for other Virtual Instruments to pass data back and forth to subVirtual Instruments. This adheres to the modular programming concept permitting an application to be divided into a series of tasks. Each task can be broken down again into simpler subtask Virtual Instruments. The

top-level Virtual Instrument then contains a collection of subVirtual Instruments representing the application function.[Ref. 7]

Since each subVirtual Instrument can be executed independently, debugging is very easy. The independent aspect also allows low-level subVirtual Instruments to perform tasks common to several applications so development of specialized subVirtual Instrument sets may be applied to a variety of user specific applications. Instead of paying for expensive updated electronic test equipment, LabVIEW's subVirtual Instruments can be changed for the cost of the programmers time.

Scientific analysis programs are not usually designed to be user-friendly. LabVIEW's ability to model the behavior of traditional benchtop instruments and create automated test sequences simplify development for the inexperienced programmer and the expert. The use of icons for building a function are light years from the mundane practice of writing hundreds of lines of code.

IV. LABORATORY VIRTUAL INSTRUMENT DESIGN USING LABVIEW

Each Virtual Instrument designed for the Electrical Engineering Laboratory is unique, but similar in function. This chapter will discuss details of Laboratory 3, Diode Circuits and Applications, and the major differences of the other Laboratory designs. Laboratory 3 was selected for the initial programming, not for easy program development, but, the requirement for simple circuit measurements and signal sources. Appendix A has each Virtual Instrument's front panel and block diagram program code. Appendix B contains the student laboratory experiments using Virtual Instruments.

A. LABORATORY 3 DESIGN

The most complicated program design turned out to be Laboratory 3 since a variety of test equipment was required to supply power and perform measurements. These included a signal generator, oscilloscope, multimeter, and two power supplies.

Laboratory 3 program design started with the existing function generator Virtual Instrument, included with LabVIEW. This Virtual Instrument was analysized, restructured, and used as the basis for the specific needs of Laboratory 3. Construction of a 500 Hz output sinewave of 10 volts peak-to-peak was the first step of restructuring.

1. Sinewave Generation

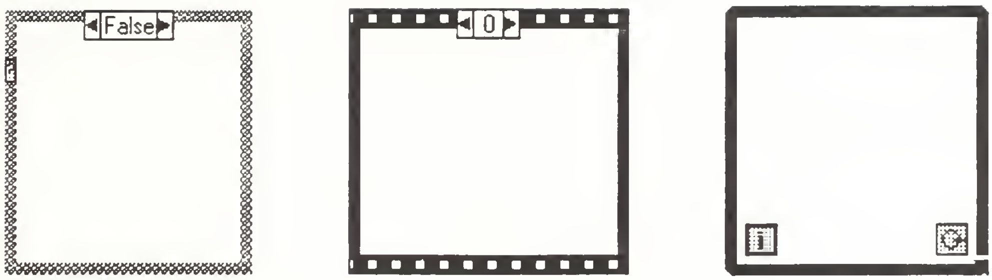
Sinewave signal generation is accomplished by using the "compute waveform" Virtual Instrument. The frequency was obtained by using a buffer length of 250 updates at a 125,000.00 point rate input to the "analog output" (AO Config on block diagram) and

"clock configuration" (Clock Config) Virtual Instruments, (125,000.00 ÷ 250 = 500). These values were used to maximize the signal resolution.

Amplitude and type of waveform was also required to generate a sinewave output. The amplitude is set by the user from a front panel digital controller limited to ±10 volts. This restriction is used throughout each laboratory Virtual Instrument designed in this thesis since the data acquisition board used has these output limitations.

The waveform is selected from a ring control which associates unsigned 16-bit integers with strings and pictures. This allows the user to choose an option from a pictured list of waveforms. The value associated with the selected item is passed to the block diagram where a case is selected from the "compute waveform" Virtual Instrument, (Figure 4.1 shows the block diagram of a case, while-loop, and sequence structure). The cases include sine, square, triangle, and sawtooth waveforms. These are generated using mathematical formulas.

Upon waveform selection, the voltage data generated by "compute waveform" is passed as a two-dimensional array to "analog output write" (AO Write). This Virtual Instrument writes the voltage data to the buffer tobe available as an output to channel zero. The buffered output is started by "analog output start" (AO Start) which calls "analog output clock configure" (AO Clock Config) for a task number to configure the output channel. Upon completion of the data sampling by a student, and stopping the Virtual Instrument, the buffer is released for new signal generation by "analog output clear" (AO Clear). Also, when the stop button is selected, channel zero is set to zero volts by "analog output write one update" (AO 1-Up).



Case Structure **Sequence Structure** **While Loop**

Figure 4.1 - LabVIEW Block Diagram Structures

2. Direct Current Generation

To produce the direct current voltage required for the experiment, the true-false case was used, (a numerical case structure may be used in a Virtual Instrument if more than two cases are required). The user places the direct current voltage desired in the DC Voltage digital controller. The true case is performed when front panel DC ON is selected. This allows "analog output update channels" (AO One Pt) to write the single voltage value selected by the user to channel one. The false case produces zero volts at channel one.

3. Signal Display Graphs

To display the input and output waveforms of the experiment, an oscilloscope display is used. In order to display a signal. the channels selected, (input and output waveforms for Laboratory 3), are applied to "analog input waveform scan" (AI Wave) along with display scale limits, device (data acquisition board used), scan rate, and

number of scans to acquire. Analog input waveform scan acquires the defined number of scans at the scan rate, and generates the voltage data for use on the transposed waveform graph.

The waveform graph transposes the array to allow proper values for the x-axis to be used as a time scale. The graph requires an array consisting of an X_0 initial value (set at 0.00), scan period, and actual voltage values acquired. These elements are assembled together by the "bundle" function into a cluster before submitted to the graph. The cluster, in the block diagram, groups related data elements to reduce wiring and connection terminals. A cluster is comparable to a "struct" in the C language or a "record" in Pascal.

The front panel waveform graph display (oscilloscope) x- or y-axis may be scaled to properly display the largest signal to interpret data. This is accomplished by using the LabVIEW operating tool (pointing finger) and selecting the maximum or minimum value of either axis, then deleting that value, and typing in the desired value.

Part of the original Laboratory 3 required the student to draw the transfer characteristic of the circuit under test, voltage-out versus voltage-in. By using the index array function, the voltage only portion of each input channel was extracted and combined to form the transfer characteristic. This is displayed by an x-y graph front panel function when the transfer characteristic switch is placed in the ON position while the Virtual Instrument is running.

4. Print Out of Front Panel and Block Diagram

The experiment's front panel indications or oscilloscope displays may be printed out by selecting "Print" from the File menu. The entire front panel or block diagram can be printed out, including the digital control and graph settings.

A Hewlett Packard Laserjet 4 was used to print out the display. The resolution was found to be much better without selecting the bit-map option from the LabVIEW print menu. Font size or label placement printing were the only obstacles to avoid. Although a front panel or block diagram on a monitor may appear to have all the labels, actual screen contents printed out sometimes left partial words. Resizing the text block or selecting a smaller font cleared these problems.

The most dramatic print outs are in color. LabVIEW block diagrams have each icon and wire type displayed on screen in a different color to help distinguish different functions. When a Hewlett Packard 1200C color printer was used for printing a Virtual Instrument, each wire could be differentiated, allowing easy trouble shooting of the block diagram.

5. Front Panel Changes While in the Run Mode

In order to allow the user to change wave pattern or the amplitude values while the Virtual Instrument is running, a true-false case structure is used. Initial Virtual Instrument output channel setup and run is the true case. The false case allows the user to change the front panel controls by waiting ⅛ of a second between front panel sampling. This conserves central processing unit time needed to simultaneously run the other Virtual Instruments for the experiment.

6. Problems Encountered

A second direct current source or a second signal generator could not be simulated by the LabVIEW board for the design of Laboratory 3. The Laboratory could include the second direct current source only if the sinewave signal was not used at the same time. The only reason a sinewave along with two direct current voltages could not be generated simultaneously is the two channel output limitation of the data acquisition board used.

A second signal generator is required since the data acquisition board uses only one clock for output signals. The experiment needed a squarewave and a sinewave of different amplitude and different frequency. The amplitudes could be controlled, but with only one output clock, two separate frequency's could not be generated. This is a hardware limitation, not software.

These two problems could not be corrected by using the data acquisition board purchased. The student must then use an additional power source and a second signal generator for two different steps of the experiment.

B. LABORATORY 2 DESIGN

Laboratory 2, Power Supply Characteristics and Design, required an ungrounded output signal from the source to test a bridge rectifier. The data acquisition board has a ground pin for all input and output channels, along with a bias return used in the differential mode. To allow an ungrounded connection, the signal output ground (AOGND) pin was attached to the rectifier and not to the rest of the circuit's ground

terminals. This allowed full bridge rectification to be observed and tested since the analog output voltages are referenced to the analog output ground pin.

Laboratory 3 was used as the core Virtual Instrument. One requirement for the experiment is to determine the direct current output voltage of the rectified signal. The Virtual Instrument acquires this by extracting the voltage array values and supplying them to the alternating current and "direct current estimator" (AC & DC Estimator). The estimator computes the direct current level of the input signal in volts, which is displayed on the front panel DC Voltage meter.

C. LABORATORY 4 DESIGN

The original Laboratory 4, Transistor (BJT) Characteristics, experiment required an ammeter to obtain current values from the circuit. The data acquisition board will only read voltage, so a 10 ohm resistor was placed in the circuit to read a voltage drop. This voltage, with the resistor value, then could be used to determine the current by using Ohm's Law, V = IR.

The design in Laboratory 4 used a single "while loop" to control the two direct current outputs and four front panel meters. The "while loop" is executed until the front panel DC switch is placed in the OFF position.

Each direct current voltage output is controlled by the DC switch. Two true-false case structures generate the voltage on channel zero or channel one. The true case uses the V_{CC} or V_{BB} knob setting input for the voltage input to "analog output update channel" (AO One Pt). The false case generates a zero volt direct current level.

The front panel contains four meter movements corresponding to V_C, V_B, V_{CC}, and V_{BB}. Each meter has an input channel connected to obtain the voltage data. Each channel's data is forwarded to the "analog input sample channel" (AI One PT) which produces the scaled analog information displayed by the meter.

D. LABORATORY 6 DESIGN

The original Laboratory 6, Transistor (BJT) Amplifier Design, experiment required a direct current voltage of 24 volts. With the data acquisition board's maximum limit of 10 volts, the circuit required re-calculation of resistor values to obtain the desired output signals.

Laboratory 3 was used to base this experiment's design. The circuit input signal waveform was not included on the oscilloscope display since the output waveforms observed are a much smaller amplitude, and the student is required to change the display to help read these small signals. By eliminating the circuits input waveform, the graph is much less cluttered.

The direct current voltage is generated the same way as in Laboratory 3. The DC meter display obtains the voltage similar to Laboratory 4.

E. LABORATORY 7 DESIGN

The major circuit component difference between Laboratory 6 and Laboratory 7, Two Stage Transistor Amplifier, is the addition of a second transistor stage with the required resistors and capacitors. The signal source and direct current voltage

requirements are identical. This allows the Laboratory 6 Virtual Instrument to be used as the basic instrument. The only modifications are on the front panel heading block.

F. LABORATORY 1 AND 5 DIFFICULTIES

Laboratory 1, The PN Junction Diode Characteristics Using a Curve Tracer, and Laboratory 5, Transistor Curve Tracing, could not be simulated with the data acquisition board purchased. In order to drive a diode or transistor into the breakdown region, voltages higher than the data acquisition boards limits are required.

Obtaining high voltages from external sources was not considered due to the safety risk involved and the data acquisition boards input limitation. No Virtual Instrument was designed for either Laboratory 1 or 5 because of this problem.

G. GENERAL LABORATORY DESIGN COMMENTS

Each Virtual Instrument Laboratory front panel includes the required data acquisition board connector pin assignments. This is a quick reference for the student or instructor to check circuit connections. The panel also has the experiment name and number, and a section for the student's name.

The student would be able to run each Virtual Instrument while viewing the front panel displays and indicators. The student would not be able to manipulate the block diagram portion of any Laboratory since LabVIEW has a function to allow saving only the front panel for running a Virtual Instrument. This prevents the block diagram portion of the Virtual Instrument from being modified by a student.

While running any of the Laboratory Virtual Instruments, if an error 10609 (transferInProg) occurs the program will halt. This is a software obstacle that LabVIEW has with the data acquisition interface using Microsoft Windows. National Instruments indicated a future version of LabVIEW will correct the problem. The error can not be avoided, but stopping, clearing, and restarting the Virtual Instrument is required.

V. FLEET IMPLEMENTATION

Is traditional benchtop test equipment obsolete in the fleet? Since the introduction of the digital voltmeter in 1963, instrument research has changed traditional benchtop test equipment dramatically.[Ref. 8] When digital instruments first appeared in the Fleet in the 1970's, repairs by Navy Electronics Technicians required less time to set up and diagnose as compared to deflection instruments. By bringing the test instrument to the equipment, a technician saved time by not disconnecting and removing the equipment from the space. But the test instrument still requires power supplied by the 60 hertz shipboard distribution system. This is a problem if the malfunctioning piece of equipment is located at the bottom of an access trunk.

A. DATA ACQUISITION SYSTEMS ABOARD NAVAL VESSELS

Data acquisition systems are now revolutionizing research and industry with more versatility, speed, and storage of test data. Several traditional pieces of test equipment can be combined into one data acquisition system to execute the various functions. Using the newest 80486 central processing unit allows the system to perform at an extremely fast rate. By employing a computer to sample data, storage of that signal data can be accomplished easily by utilizing the hard drive or floppy disks.

If periodic equipment signal samples are retained on disk, an automatic history of the equipment can be maintained by placing the data into a spreadsheet. By comparing the history files, equipment trends can be carefully observed and regulated. This data can

then be used to help monitor equipment deterioration and avoid catastrophic failures by using analysis software to predict time of replacement.

Data acquisition systems help eliminate shipboard weight since less equipment is required to do the same job. Less space is required for storage since there are fewer articles to store. And the cost is less than the required number of individual pieces of test equipment.

Downsizing of the Navy means less personnel to run a ship. Data acquisition systems can assist one person acquire data, run the tests, analyze the data, and generate a report. After obtaining the data, most of the work can be accomplished in a workspace, office, or anywhere away from distractions. By sending the data to a shore facility, fleetwide facts can be collected and diagnosed to help determine trends for classes of ships or particular equipment to aid in budgeted funds allocated for maintenance. It is easier to know in advance any negative trends in equipment to help plan money needed to repair or replace.

Although it is easier to implement a new system on board new construction, data acquisition systems are not that complicated, and do not require complete overhaul of existing equipment in order to use it. Ships under construction do not have to be the only ones to benefit from a data acquisition system. Existing ships may benefit more from a data acquisition system by using one to replace broken or missing test equipment. Budget cuts usually mean operations still continue, but maintenance funds suffer.

B. PREVENTIVE MAINTENANCE SYSTEM ADVANTAGES

Certain Preventive Maintenance System (PMS) checks can benefit since the technician will spend less time performing a check, and could accomplish more work in one day. The data acquisition system can serve as a weekly, monthly and quarterly report generator for completed PMS checks.

Actual PMS cards could be included on a separate disk. Equipment needed and each step to perform would be displayed on the screen when a check was selected. Upon reaching any step that requires observing an electrical signal, the data acquisition system would transform into the specific test equipment. Once the data is obtained, the system would revert back to the next PMS check.

Another variation could have two screens displayed simultaneously, one with the test equipment Virtual Instrument, and the other with the PMS card. This would allow the operator to perform the test and read previous steps, but not change screen views completely and distract the operator.

Each PC has an internal clock which could provide a time stamp for PMS completion. This would be logged automatically when the check is finished, avoiding sailor forgetfulness. In order the cheat the system, a technician would have to alter the system clock. This can be refrained from by using password protection for access to system parameters.

C. SUITABILITY FOR SHIPS

Backup power for a laptop data acquisition system is just another battery pack, so shipboard power losses are not a problem. But using a laptop system in a damage control environment may have drawbacks. Electricians need a meter to verify power loss. A data acquisition system may not suit the requirement for having a meter in a repair locker.

Surge protection is only required for the battery charger or base unit since the laptop is portable. The laptop can be carried to the equipment to perform diagnostic tests and data gathering.

Each class of ship or major piece of equipment could have custom designed displays and reports that would require less paper work for file maintenance. By using software generated forms, the Navy could update form layout much faster, since there would not be a need to deplete the stock of old forms in the fleet. This alone is a substantial savings, because there is no need to have expensive printing services for every form update or correction.

Deploying new or updated weapons systems or machinery in the fleet requires special attention to certain variables for monitoring proper operation. The required report information will change over the life span of that piece of equipment. Once the equipment has 'broken in,' a new set of data is usually required. By having software forms used, changing report information would be easier. The previous data collected would still be retained and implemented in a history file.

D. TRAINING

With each piece of new test equipment, operator training is required. A computer data acquisition system could use a Virtual Instrument as an instructor for a self paced course on signals and data gathering. Informative assistance tutorials included on a data acquisition system would allow sailors to 'open a new screen' and view details on obtaining signals that may have been forgotten. The sailor may now perform fewer mistakes for lack of asking questions of supervisors, but looking at a help screen.

The data acquisition system software could be structured with sections containing information on signals, report generation, equipment trends to be aware of, and warning signs of equipment failure. The PC can also be used for the usual functions of word processing.

With shipboard divisions having a vast assortment of equipment to maintain, very little time can be spend learning each piece's peculiarities. Having a system with a history immediately available to brief a person would enhance any classroom knowledge gained. Using computer equipment history data to expand experience can only promote a more efficient running ship.

E. OBSTACLES TO OVERCOME

One big disadvantage of data acquisition systems in the military is calibration. Although a data acquisition board's EEPROM is calibrated at the factory, can a ship perform a check on that calibration standard? Will the system have to be sent off for fine tuning at a regular interval, and waste more time, or, can a ship have electronic standards

for in-house calibration? Any data acquisition system replacing test instruments will cut the number of items requiring calibration.

Rugged industry PCs are currently being produced that meet mil standards, and can withstand shipboard abuse. But weight and dimensions must be minimized to avoid risk of damage and disturbance from transporting it from shop to equipment when going through small accesses.

One data acquisition board is not able to control a magnitude of ranges of current and voltage aboard ship. Voltages encountered are from a few microvolts for antenna signals, to hundreds of volts experienced in a ship distribution system, and currents can be found with the same extremes. If a data acquisition system is employed, several acquisition boards would be required, one for low value acquisition, another for medium values, and one for high values. The boards could all be inside one computer in a repair shop, or installed within several laptop computers. Each laptop could be used for a specific range of values, similar to multimeters and power supplies. This does not limit a data acquisition system, but expands the capabilities of the system, allowing greater flexibility.

The ultimate design would have a special adapter on the machinery to plug the data acquisition system into, like automobile diagnostic hook ups, to determine if the equipment is defective, and then diagnose the problem. This would be similar to the system found on new aircraft.

The quantities of electronics encountered on board a naval vessel vary so much in variety and magnitude that a data acquisition system can become a universal instrument

having a very large measuring range. It may not eliminate every piece of test equipment, but the advantages for replacing most out weigh any disadvantage.

VI. CONCLUSIONS, RECOMMENDATIONS AND FUTURE RESEARCH

A. CONCLUSIONS

The requirement to build and implement a data acquisition system for the Electronics Engineering course laboratory was achieved and generated considerable enthusiasm from staff and students. The selection and use of available software and hardware proved to be a substantial improvement over the current manual hook-up of test equipment and test circuits.

Designing a single screen Virtual Instrument for input and output of various experiment signals proved to be a challenge. One goal was not to have a student flip between computer screens to run an individual step of an experiment. Everything for that step, function generator, oscilloscope input and output signals, and direct-current voltage, should be available on one screen for viewing and adjusting.

Design of each Virtual Instrument started with the presently used test equipment. By looking at the experiments and determining the functions used on the test equipment, portions of the equipment simulated that had no influence on the experiment were eliminated. Software based instruments have the ability to place only the functions and controls one would want on the Virtual Instrument. The customization available for each application is one of the best advantages of using a Virtual Instrument.

1. Computer System

When this thesis was first envisioned, all existing test equipment for the Electronics Engineering laboratory was believed to be replaceable with data acquisition systems. Once the equipment was purchased, some limitations were found. The largest problem was not being able to simulate a curve tracer, the most expensive piece of test equipment to replace.

Although curve tracer fundamentals can be imitated with this system, the high, 200+ volt, requirement to drive a diode or transistor into its breakdown region was not feasible for duplication. External power supplies, to provide the high voltage, were ruled out due to the extreme safety hazard posed to personnel. Future experiments simulating a curve tracer appear to be limited. Simulations of the curve tracer's output can be displayed by the data acquisition system. But the student would not be able to acquire the actual parameters of the specific transistor they would use in the design an experimental circuit.

At the time of selecting a data acquisition board, no company, from whom the board might be purchased, suggested or required a particular brand of computer or peripheral equipment. The only selection guidelines given were whether to use IBM PS/2s, IBM clones, or Apple Macintoshes. IBM clones were selected, not only due to limited funds, but also because most students have experience using an IBM type computer. Another factor was the proposed expansion of using this software in other engineering laboratories to facilitate standardization of Virtual Instrument based experiments.

Out of the eleven computer systems purchased, 5 computers had one or more defects, see Table 7-1. Observe from the table that one computer did not boot-up directly out of the box. It was wondered how that system was tested prior to shipment. It should be noted that these were computer systems purchased new, to be used exclusively for this laboratory.

Testing of the computers isolated most defects. These defects were placed into the three computers suspected of bad motherboards and sent back to the company. The computers have returned and there is still a problem with two, they do not run the LabVIEW software correctly. This appears to be the motherboard's tolerance level, since all computer systems are identical, and swapping parts does not solve the problem. Diagnostics performed on the system did not find any flaws with either computer, but the problem still exists. Isolation of the actual area of fault is beyond the scope of this thesis. The remaining computers have had no difficulty running LabVIEW, the applications, or the acquisition board.

TABLE 7-1 - COMPUTER FLAWS

Number of Computers	Problem
2	Hard Disk Drive/Controller Failure
1	Bad SIMM
1	Would Not Boot Up, New From Box
2	Not Compatible With Acquisition Software
1	Will Not Boot Into LabVIEW From Windows
1	Bad 3½" Disk Drive
1	Auto-Rebooted, Independent of Operator

2. Software

Finding a compatible software for the desired acquisition board was not a problem for use with this thesis. The same company, National Instruments, was selected for both. Although there are many companies with similar acquisition software, LabVIEW offered substantial savings since it was purchased for educational use.

All Virtual Instruments were created referencing the user manuals. The simple hook up of icons to develop a Virtual Instrument showed that the software is very user friendly for non-programming type people. The nine user manuals gave an in-depth logical understanding of how to develop and run Virtual Instruments. Virtual Instrument design, using icons, was much easier than writing hundreds of lines of code to perform the same function. The software performed better than anticipated for the laboratory experiments.

3. Hardware

The acquisition board selected did not have an adequate number of output channels for some of the experiments. The board selected could produce the signals, but the number of signals was not taken into account for each particular experiment. The board used had a sufficient number of input channels, but having only two output channels did limit a few experiments. One required an additional external power supply to complete the testing. This could have been avoided by more research comparing each experiment's requirements with the available boards specifications.

4. Laboratory

The finite time available and limited offering of the course prohibits this thesis from any practical analysis of Virtual Instrument designs. The practical application will come from the student using and comparing the computerized test methods with their experience employing benchtop test equipment.

The system was demonstrated to, and used by, the laboratory technicians who found the simplicity of running a Virtual Instrument enjoyable. They commented that the data acquisition system with the LaserJet output was a big improvement over setting up and adjusting test equipment, and manual sketching of waveforms. It was also noted that the laboratory experiments were completed faster by using a software based system.

A few students were asked to run several experiments using the data acquisition system and compare it to the manual method. The student opinions were all favorable towards the data acquisition system. They commented positively of the ease of use, speed of hook-up, high quality output, and simple signal selection. The only

minor item of criticism was the combinations of color for the screen. These were changed to help distinguish input and output signals.

B. RECOMMENDATIONS

1. Computer System

The problem with purchasing computers from a modest business, is their quality margin for selling small quantities of items. Due to the limited volume of sales, some small businesses make money by installing products with a marginal quality level. If one part is tested alone, the part would not fail very often. But combine a multitude of marginal pieces together and the system fails frequently. This degrades system reliability many more times than using a single marginal part.

It is recommended that complete specifications for at least the motherboard, central processing unit, input/output controllers, video cards, and random access memory be included in the purchase order to eliminate a vendor using less than desirable parts. It is noted that just specifying particular items will not guarantee the part is premium quality, but the odds are more in favor of having a total system that responds as anticipated.

2. Software

No recommendation is required for the software since it performed beyond expectations. It was not shown whether purchasing from the same manufacturer of the data acquisition board had any advantage over purchasing compatible software from a different vendor. There was no other acquisition software/hardware combinations

available to test and compare. No problem was encountered, or expected, with the compatibility of the selected board and software operating together.

A bonus to the software would be to include sound. Although it is not needed by this laboratory, other courses study amplifiers and soundwaves. The ability to use a data acquisition system with an audible feature could enhance the student's ability to understand some electronic and soundwave principles. But this feature is best implemented into the software by the manufacturer.

3. Hardware

If a data acquisition board is under consideration for a laboratory course, it is recommended to select a board with higher resolution and a greater range of selection for voltage and current. Safety considerations need to be looked at closely if values are needed above 35 volts and 0.1 amperes.

4. Laboratory

The entire laboratory setup needs to be tested under full utilization by a class. Until the laboratory setup is completely running in a student environment it cannot be determined if each Virtual Instrument has all flaws eliminated. Finding faults in the setup is easier if the software is placed in everyday use.

The laboratory has the capability for a tutorial designed to step through a Virtual Instrument session. This would be especially suited if more than one class or department standardizes laboratory software. By using one main acquisition software for

a variety of engineering classes, quarterly student software learning curves are eliminated allowing more time for instruction of course material.

C. FUTURE RESEARCH

The software and hardware selected for this thesis is also available for Sun workstations. Future research could determine if using a workstation for a student laboratory is feasible. Setting up a workstation laboratory using data acquisition software and hardware with specialized signal analysis software could result in rapid thesis design applications. A drawback is the possible high cost.

Actual application of a data acquisition system using laptop computers on board a naval vessel would be another area of future research. Elimination of equipment and cost reductions, as noted in this thesis, can be directly applied to implementing this system on board a ship.

If a laboratory requires use of specialized pieces of test equipment, VXIbus (VME extensions for instrumentation bus) components should be researched. This instrument-on-a-card standard was introduced in 1987. They are high-performance, sophisticated instruments that combine with GPIB (General Purpose Interface Bus) equipment and data acquisition boards. Combining these instruments with data acquisition software can expand electronic research areas.

1. Further Applications

Most colleges or universities do not need highly technical measuring devices for basic electronics laboratories. The signals generated and tested are very ordinary,

usually 60-1000 hertz and ±10 volts. Any mechanical or electrical laboratory having signals with these characteristics should look into using a data acquisition system to produce the signals. The prime purpose of a basic electronics laboratory is to experiment with elementary electronic devices. Having a data acquisition system reduces the drudgery of hooking up test equipment and increases the quality of student experiment output.

If more classes or departments use the same data acquisition systems, active learning could be incorporated by making laboratory exercises interactive between them. The school could have integrated engineering workstations designed to increase development productivity.

The Navy Electronics Technician and Electrician 'A' and 'C' schools, and other Navy electronics schools, could also benefit by using a data acquisition system over benchtop instruments. Although the data acquisition system is not currently in the fleet, learning test equipment fundamentals through Virtual Instruments has many advantages over benchtop test equipment. The benefits discussed throughout this thesis apply.

LIST OF REFERENCES

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3. Dakin, C. J., and Cooke, C. E. G., *Circuits for Digital Equipment*, p. 11, Iliffe Books, Ltd, 1967.

4. Beerens, A. C. J., *Measuring Methods and Devices in Electronics*, pp. 33-34, Hayden Book Company, Inc., 1966.

5. Sedra, A. S., and Smith, K. C., *Microelectronic Circuits*, pp. 2-8, Sanders College Publishing, 1990.

6. National Instruments Corporation, *AT-MIO-16F-5 User Manual*, pp.2.23-2.25, July 1993.

7. National Instruments Corporation, *LabVIEW for Windows User Manual*, pp 1.1-1.10, August 1993.

8. Allocca, J. A., and Stuart, A., *Electronic Instrumentation*, p. 3, Reston Publishing Company, Inc., 1983.

APPENDIX A - FRONT PANEL DISPLAY AND BLOCK DIAGRAM

This Appendix contains the front panel display and the associated block diagram as viewed by the user. Each front panel printout shows the switch and oscilloscope placement, and the initial control knob and indicator settings. Actual placement of each front panel component on the screen does not affect any block diagram wiring. Deletion of a front panel switch or display will cause the associated block diagram icon to disappear also, causing a broken run time arrow. The Virtual Instrument will not function until the faulty wiring or missing item is replaced. For these reasons the Laboratory user front panel has been saved in a run only mode, no modification to the panel will be able to be saved by the user.

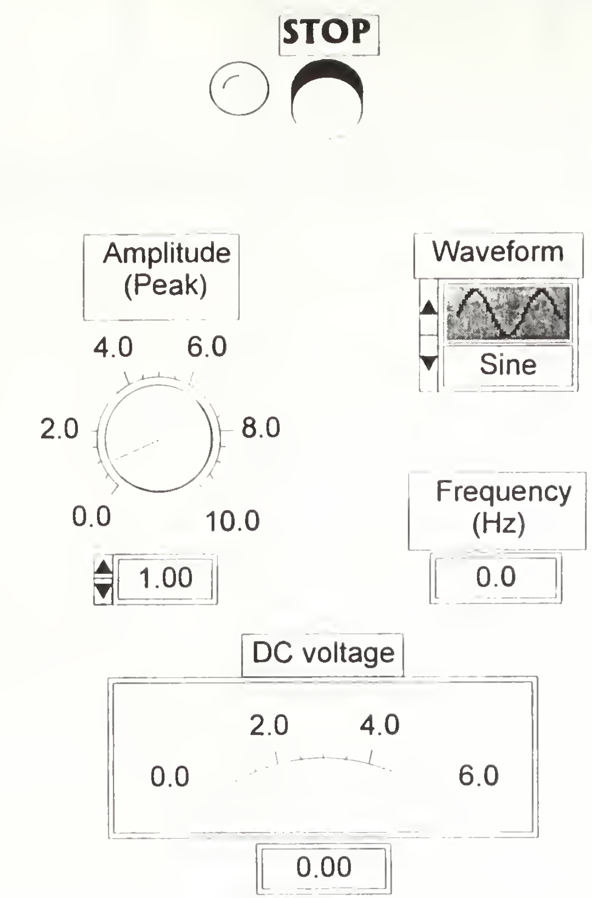
TJS GRAPHICS 94

EC 2200 Laboratory Experiment 2
Power Supply Characteristics and Design
Naval Postgraduate School

Date ________________

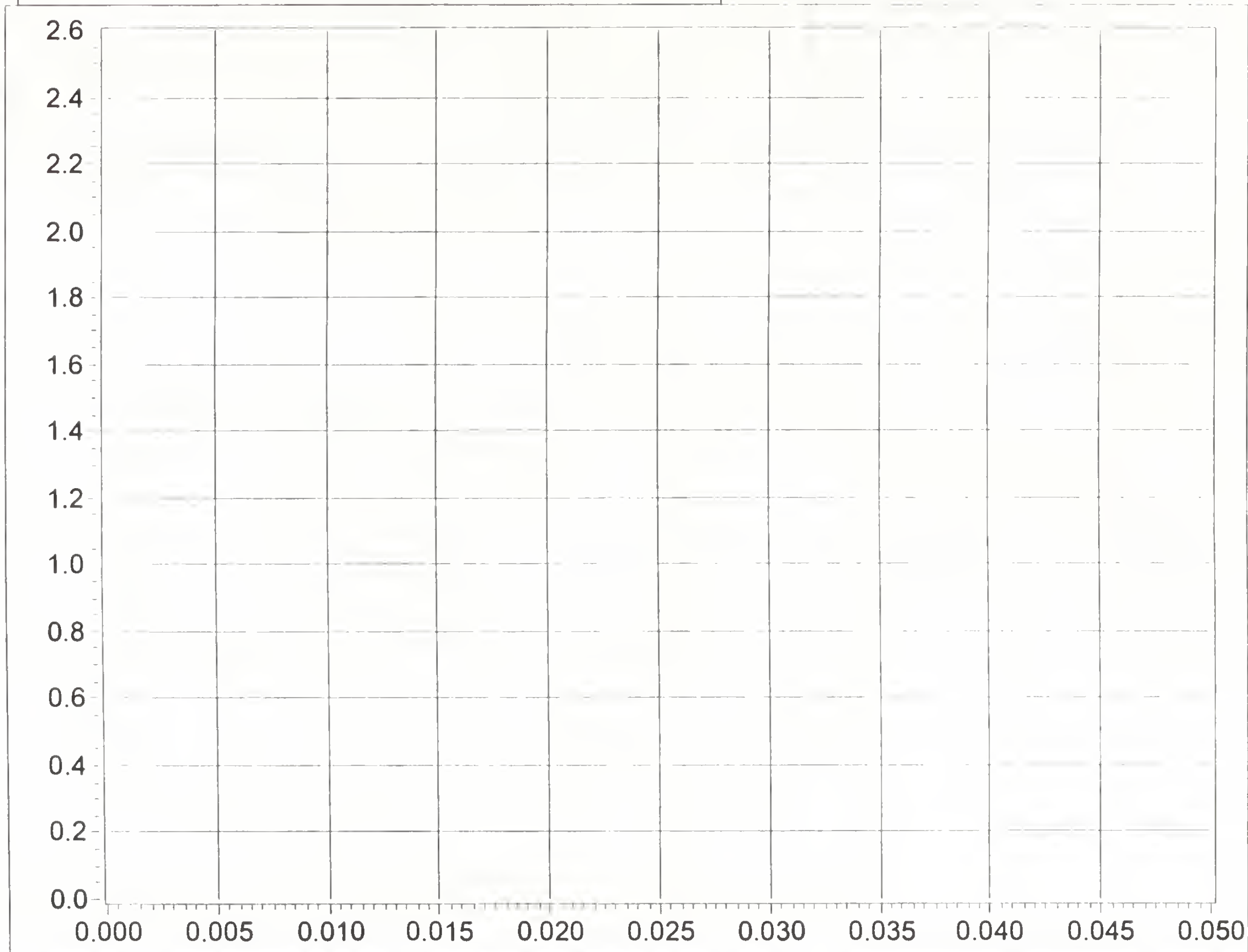
Name ______________________________

____

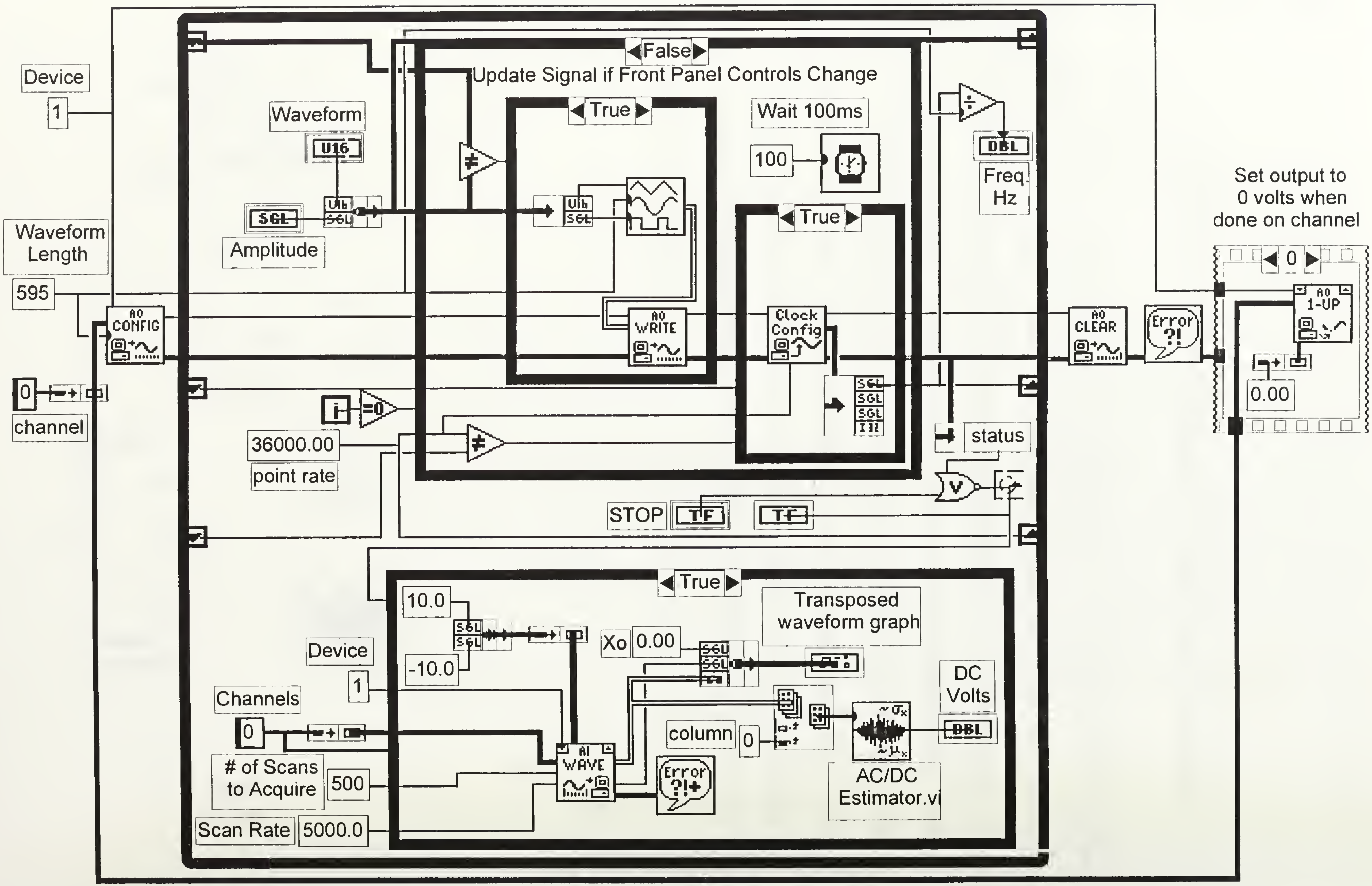


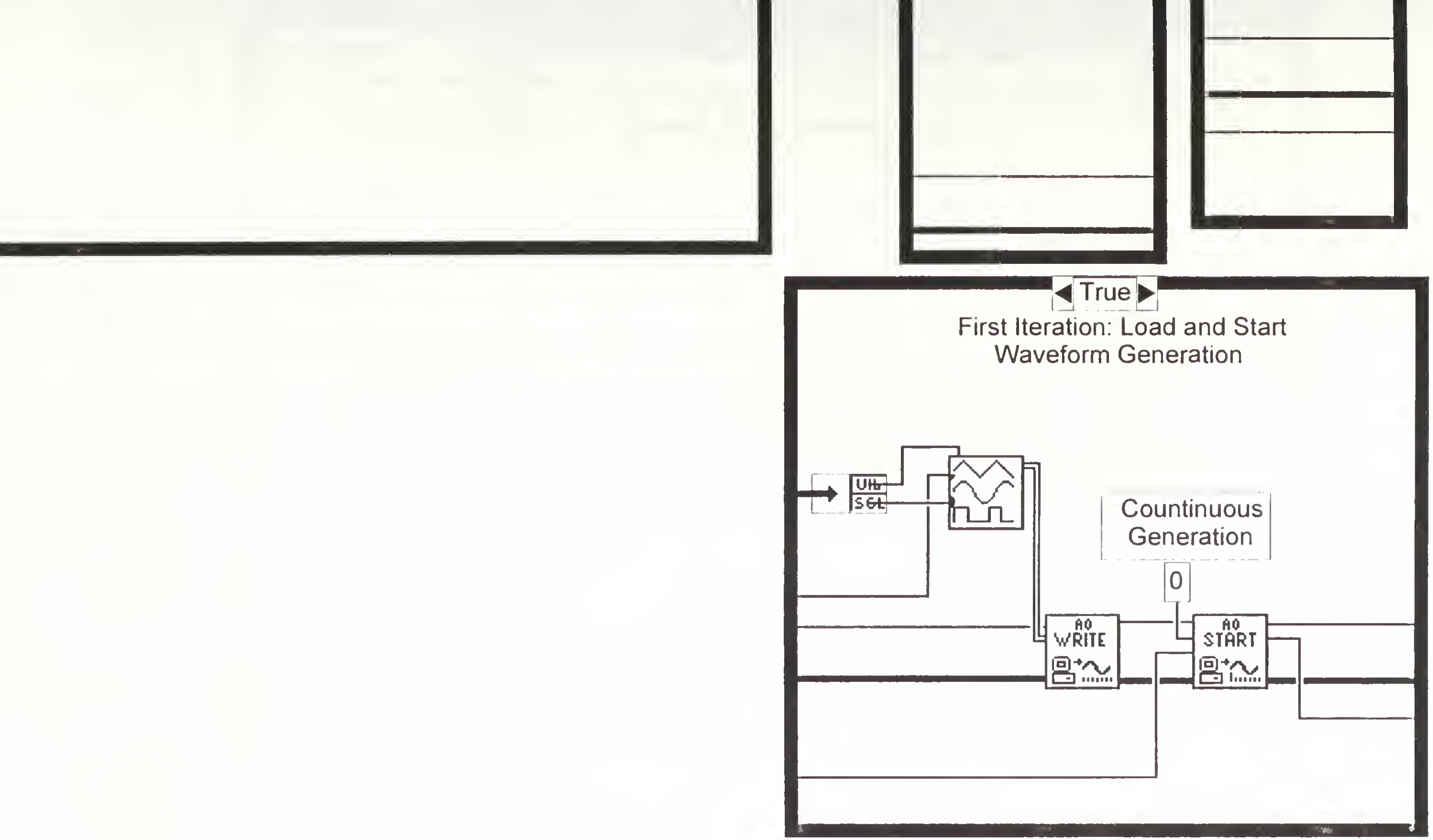
Pin Layout

Output - Pin 20
Input - Pin 3
Output GRD - Pin 23
Input GRD - Pin 4



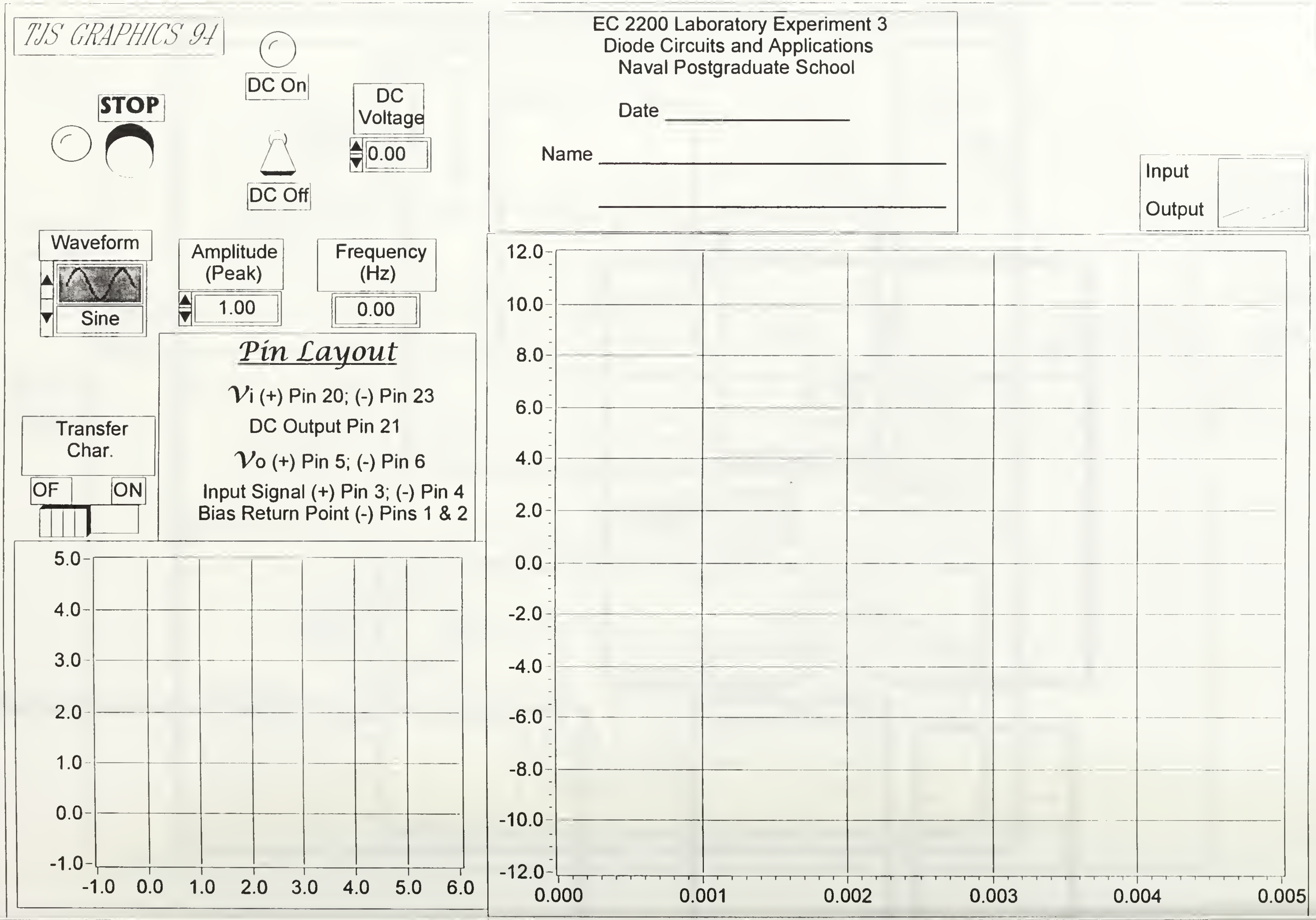
lock Diagram

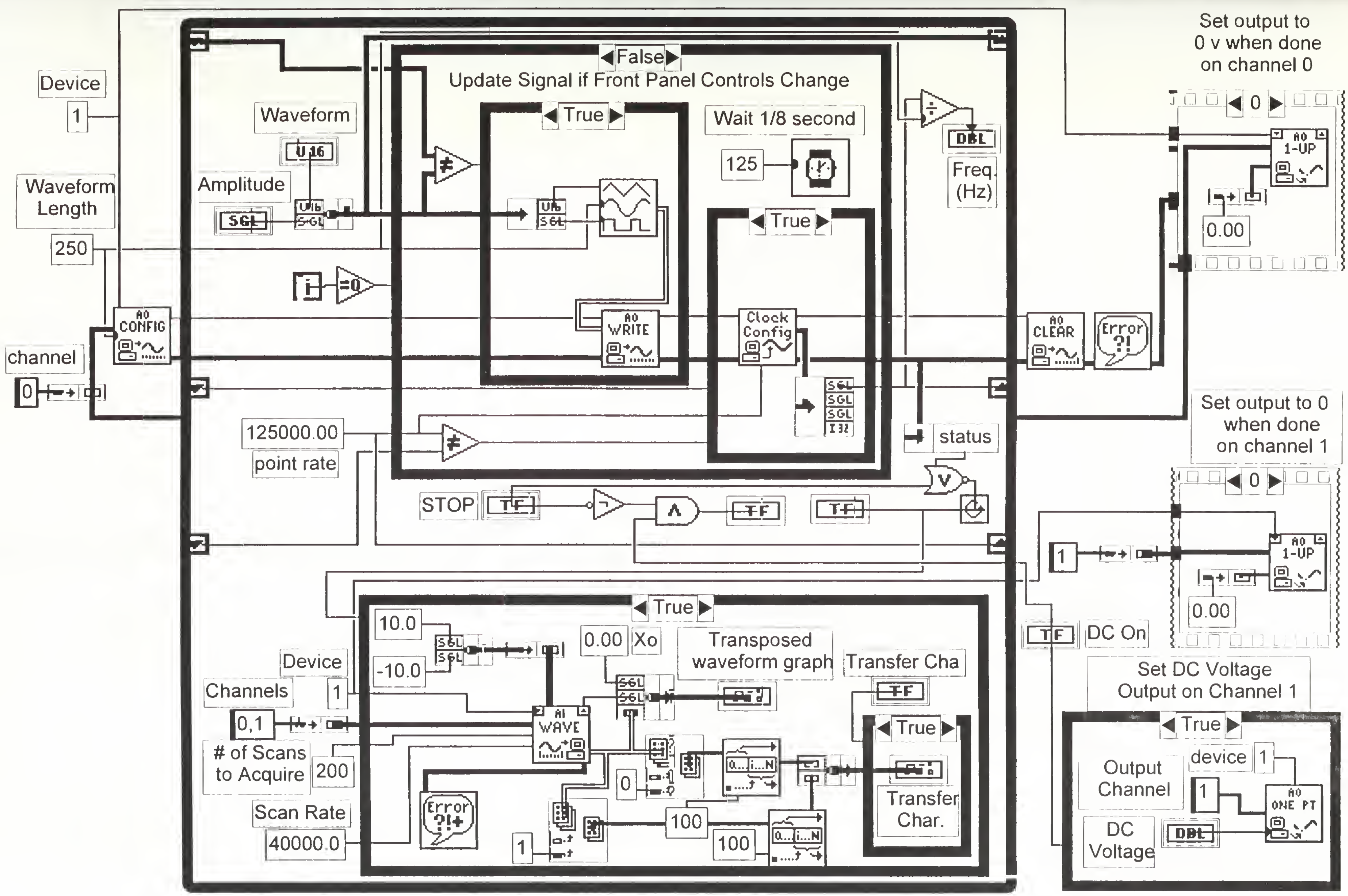




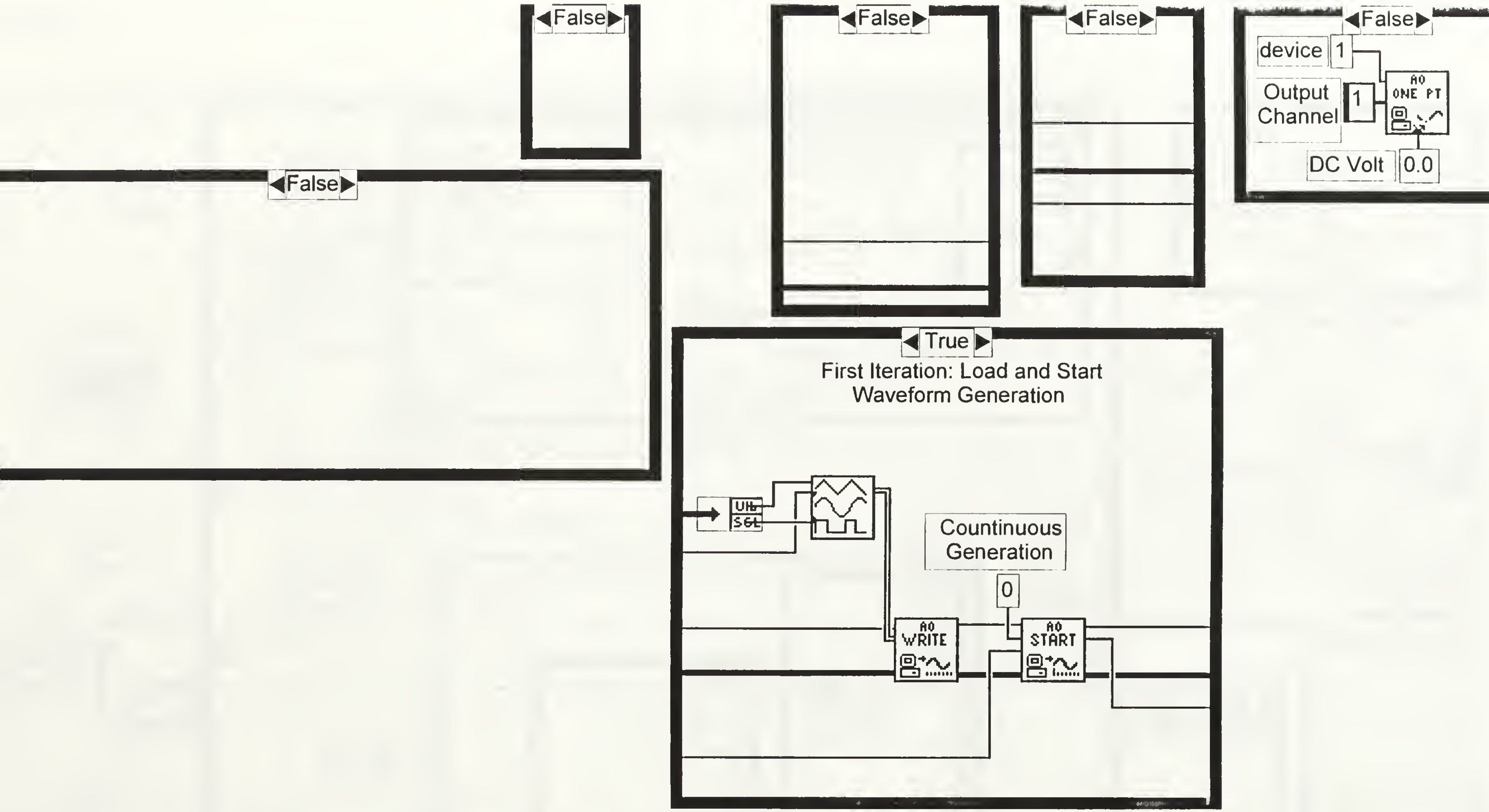
True
First Iteration: Load and Start
Waveform Generation
Countinuous
Generation
0
AO
WRITE
AO
START

Front Panel


TJS GRAPHICS 94
STOP
DC On
DC Off
DC Voltage
0.00
Waveform
Sine
Amplitude (Peak)
1.00
Frequency (Hz)
0.00
Transfer Char.
OF
ON
Pin Layout
Vi (+) Pin 20; (-) Pin 23
DC Output Pin 21
Vo (+) Pin 5; (-) Pin 6
Input Signal (+) Pin 3; (-) Pin 4
Bias Return Point (-) Pins 1 & 2
EC 2200 Laboratory Experiment 3
Diode Circuits and Applications
Naval Postgraduate School
Date
Name
Input
Output
5.0
4.0
3.0
2.0
1.0
0.0
-1.0
-1.0
0.0
1.0
2.0
3.0
4.0
5.0
6.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
-2.0
-4.0
-6.0
-8.0
-10.0
-12.0
0.000
0.001
0.002
0.003
0.004
0.005



Device
1
Waveform Length
250
channel
0
AO CONFIG
Waveform
Amplitude
False
Update Signal if Front Panel Controls Change
True
AO WRITE
Wait 1/8 second
125
True
Clock Config
Freq. (Hz)
AO CLEAR
Error
status
125000.00
point rate
STOP
Set output to 0 v when done on channel 0
AO 1-UP
0.00
Set output to 0 when done on channel 1
1
DC On
Set DC Voltage Output on Channel 1
Output Channel
device
DC Voltage
AO ONE PT
10.0
-10.0
Device
Channels
0,1
# of Scans to Acquire
200
Scan Rate
40000.0
AI WAVE
0.00
Xo
Transposed waveform graph
Transfer Cha
Transfer Char.
100

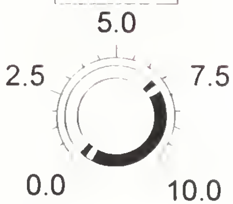

False
False
False
False
device
1
Output
Channel
1
AO
ONE PT
DC Volt
0.0
False
True
First Iteration: Load and Start
Waveform Generation
Countinuous
Generation
0
AO
WRITE
AO
START

TJS GRAPHICS 94

DC On

DC Off

$\mathbf{V}_{BB}$ Voltage



0.00

$\mathbf{V}_{CC}$ Voltage

0.00

EC 2200 Laboratory Experiment 4
Transistor (BJT) Characteristics
Naval Postgraduate School

Date ______________

Name ______________________________

____

Pin Layout

V_{BB} Input Pin 20 (+)

V_{CC} Input Pin 21(+)

Meter Measurements:

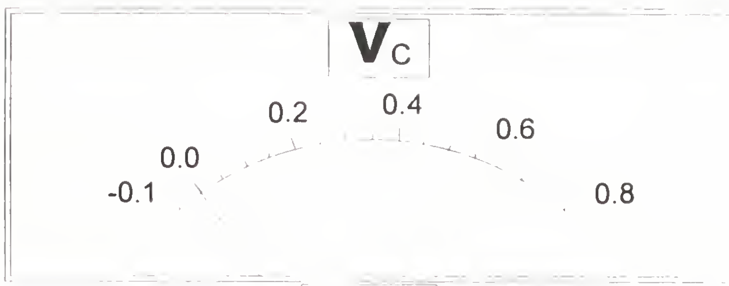
$\mathbf{V}_{CC}$ Pin 3 (+)

$\mathbf{V}_{BB}$ Pin 5 (+)

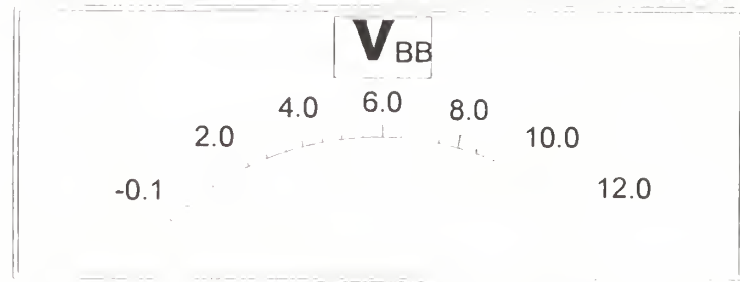
$\mathbf{V}_{BE}$ Pin 7 (+)

$\mathbf{V}_{CE}$ Pin 9 (+)

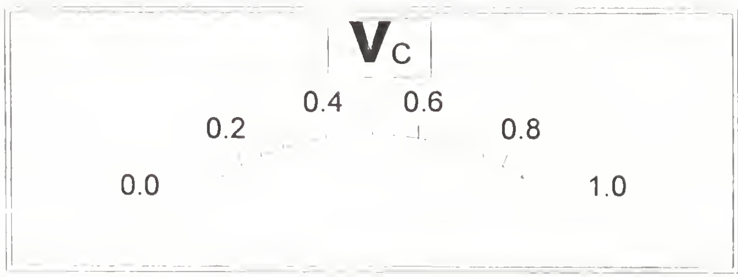
GRDs:
Pins 1,2,4,6,8,10,23



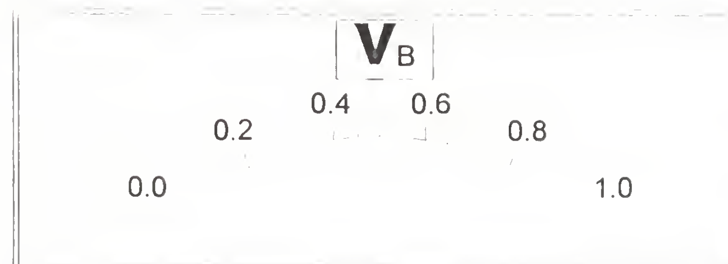
0.000



0.000

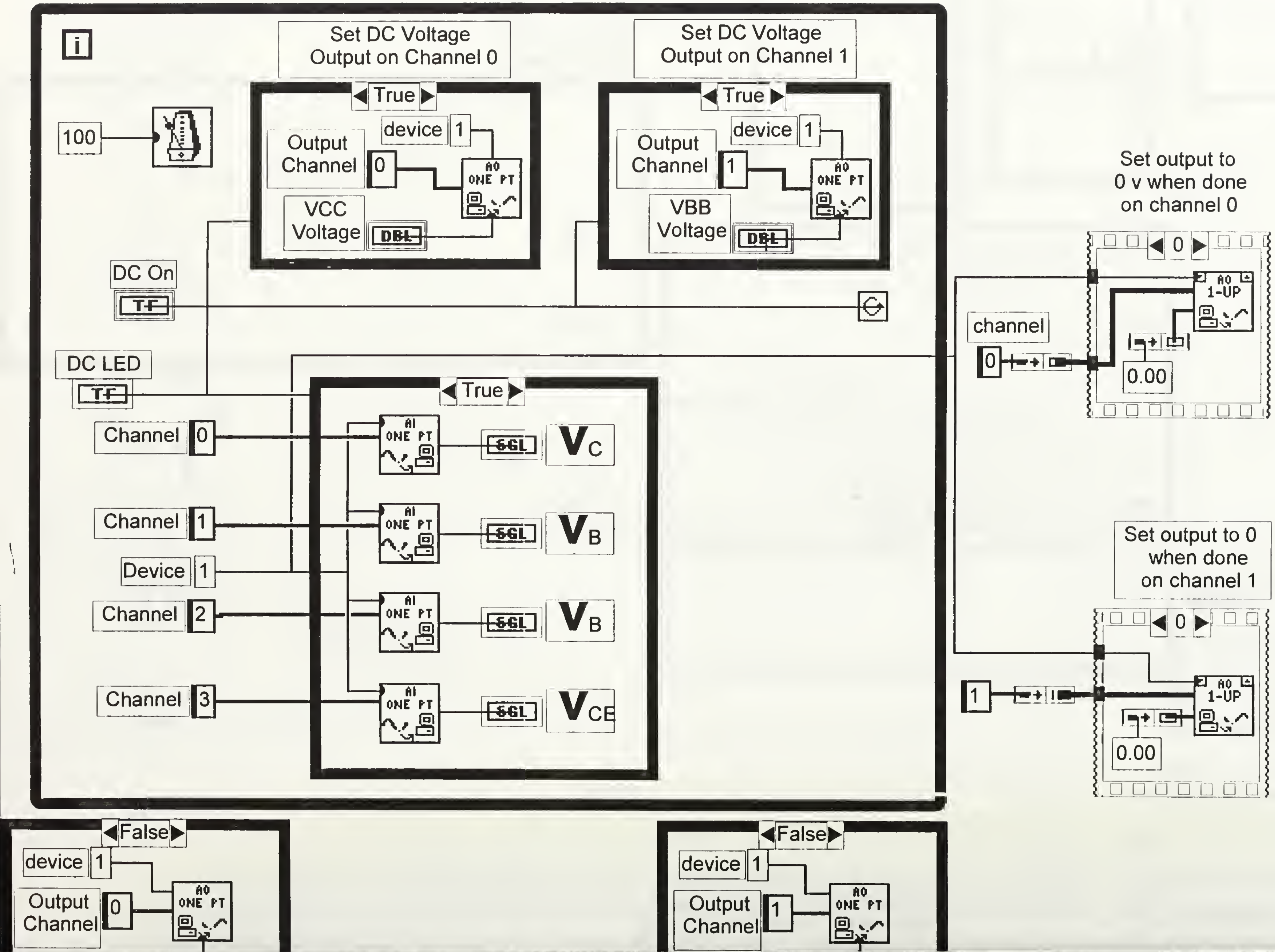


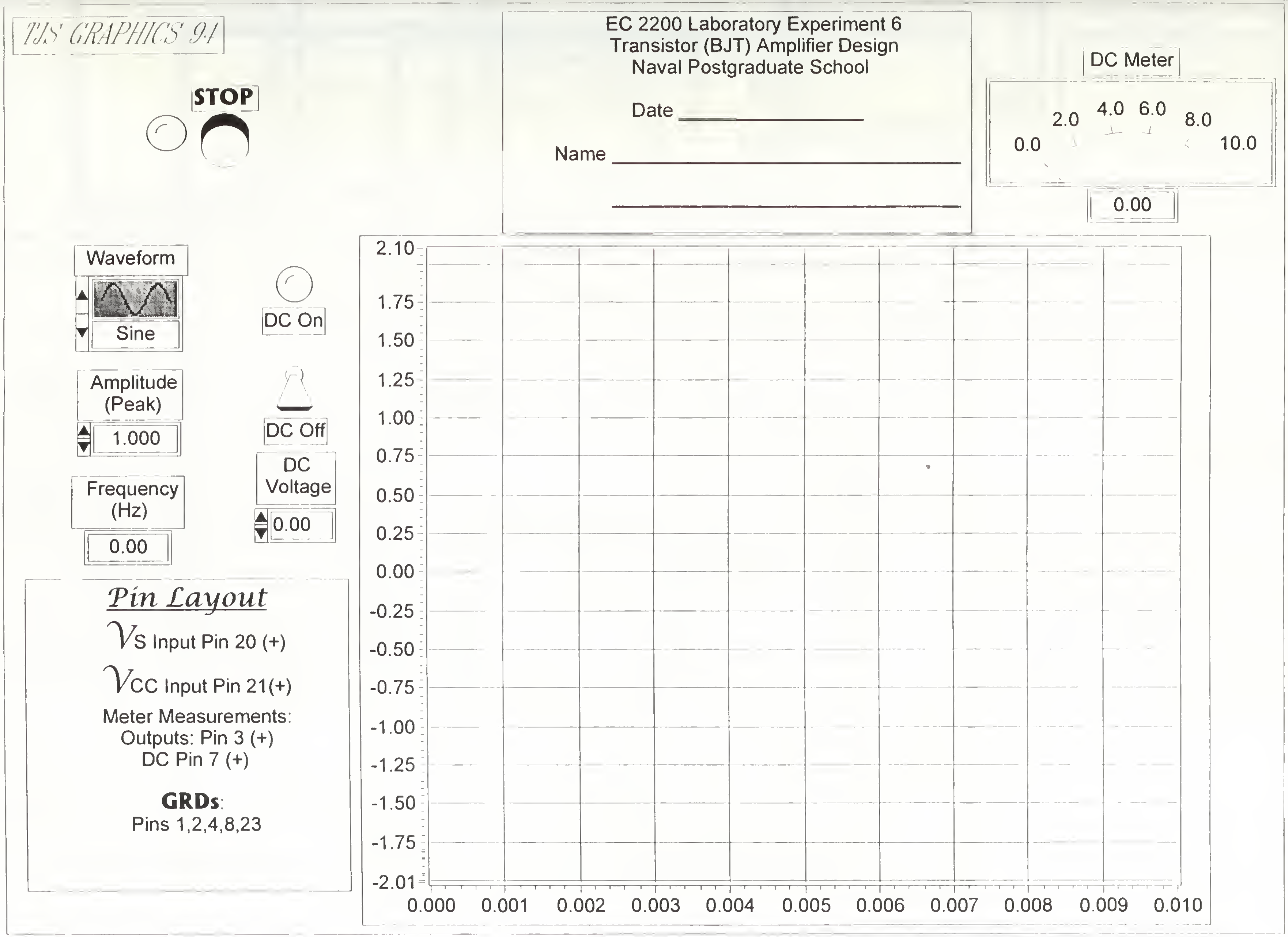
0.000



0.000

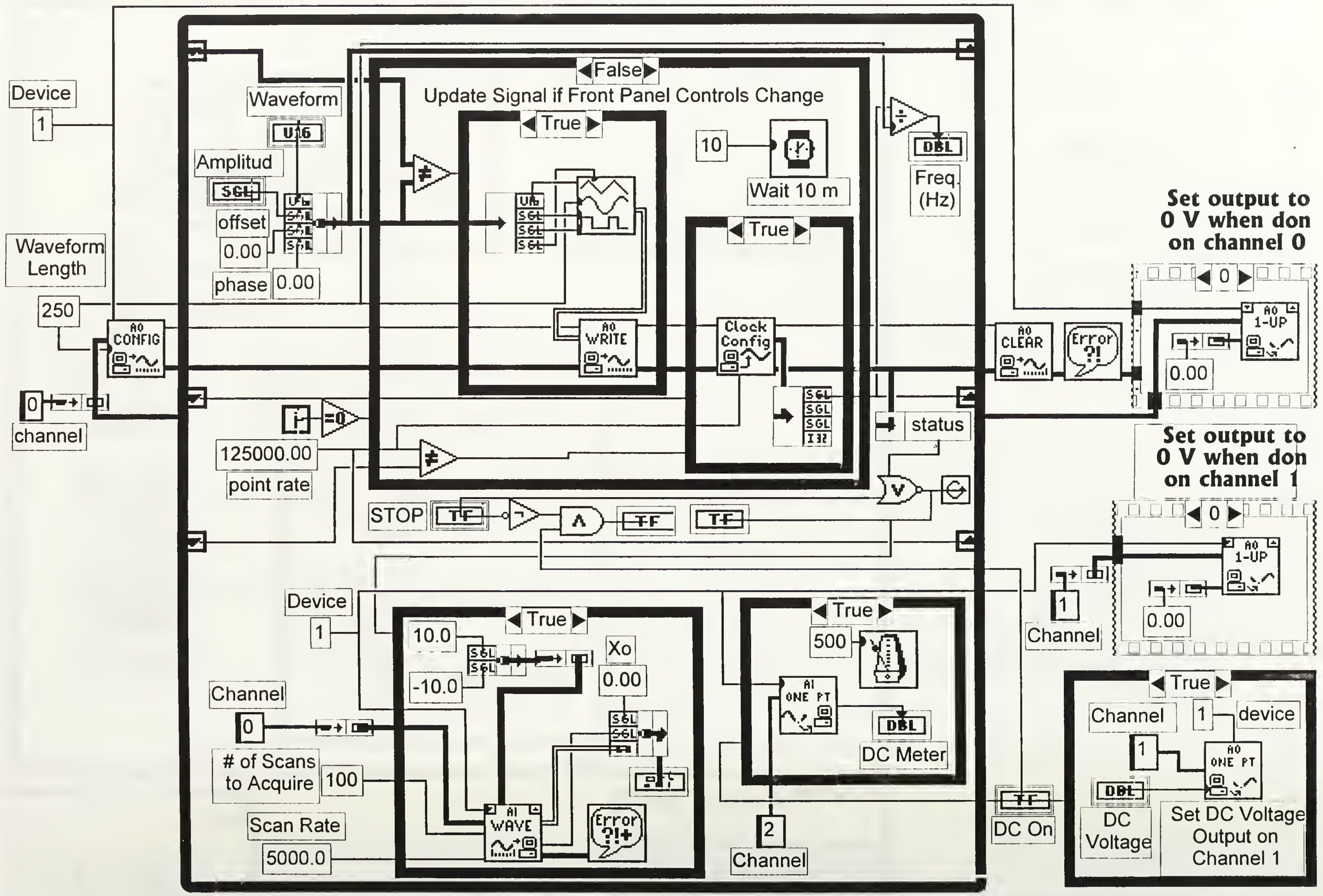
Block Diagram

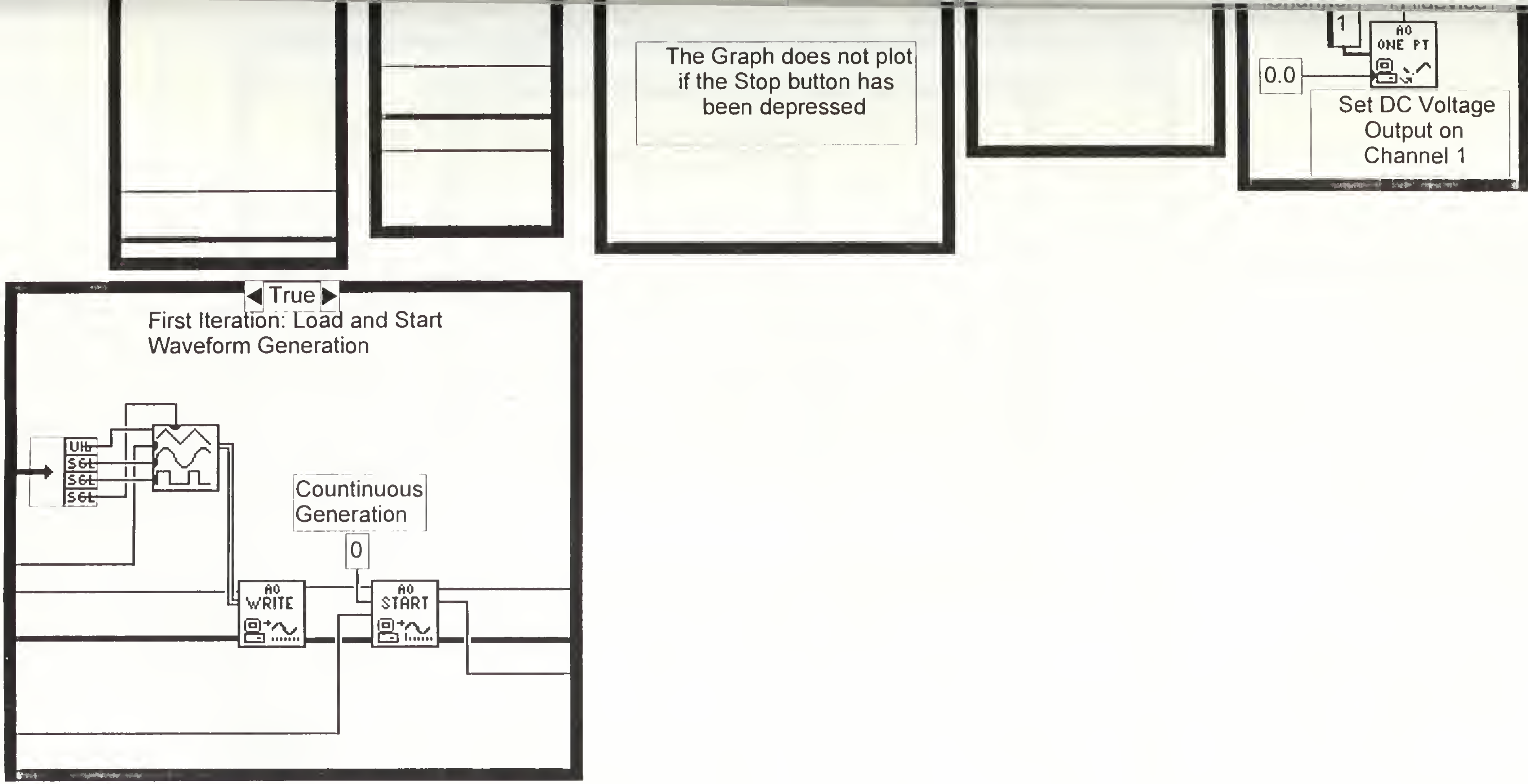




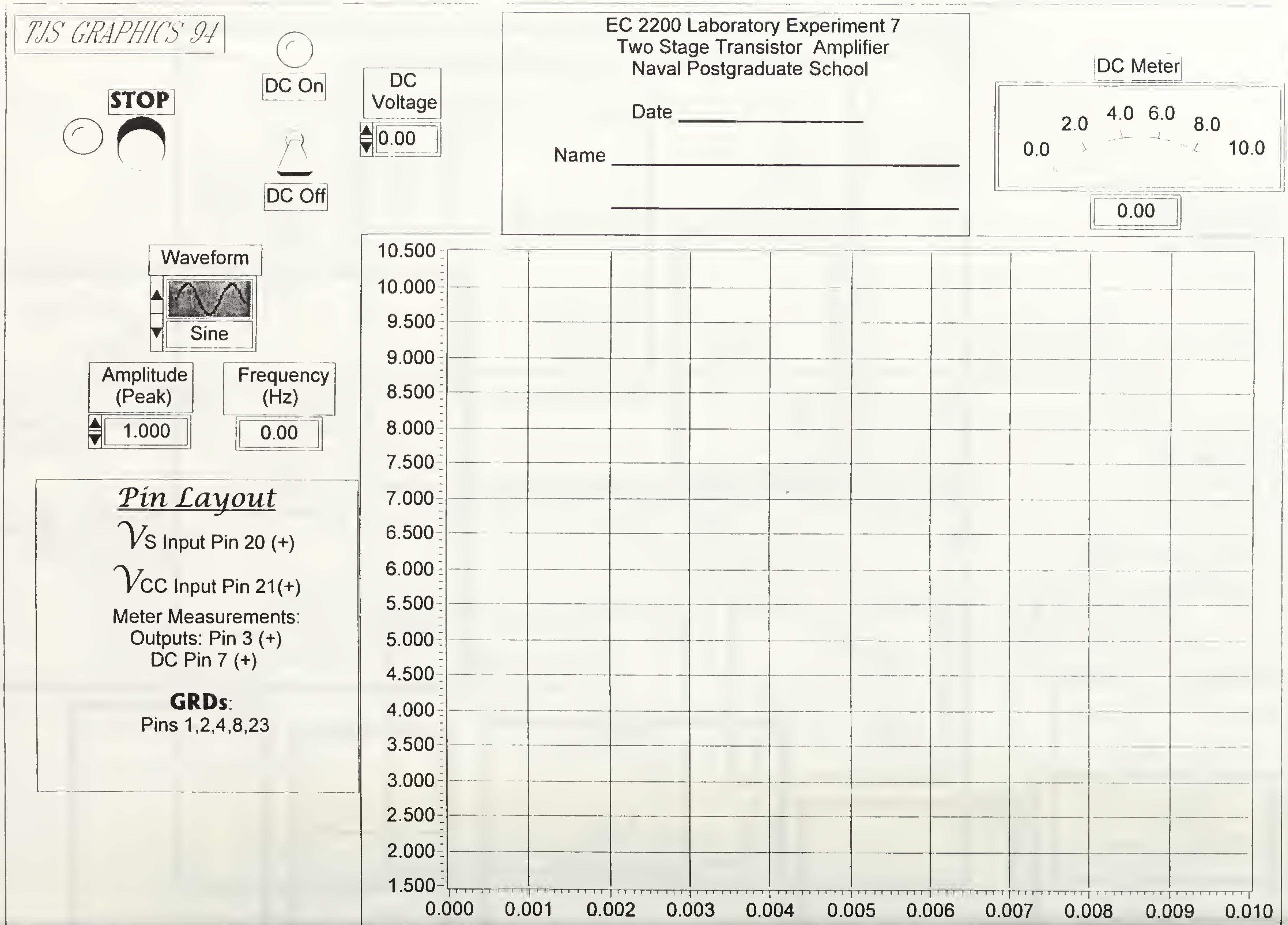
TJS GRAPHICS 94
STOP
EC 2200 Laboratory Experiment 6
Transistor (BJT) Amplifier Design
Naval Postgraduate School
Date
Name
DC Meter
0.0
2.0
4.0
6.0
8.0
10.0
0.00
Waveform
Sine
DC On
Amplitude (Peak)
1.000
DC Off
DC Voltage
0.00
Frequency (Hz)
0.00
Pin Layout
VS Input Pin 20 (+)
VCC Input Pin 21(+)
Meter Measurements:
Outputs: Pin 3 (+)
DC Pin 7 (+)
GRDs:
Pins 1,2,4,8,23
2.10
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
-0.25
-0.50
-0.75
-1.00
-1.25
-1.50
-1.75
-2.01
0.000
0.001
0.002
0.003
0.004
0.005
0.006
0.007
0.008
0.009
0.010

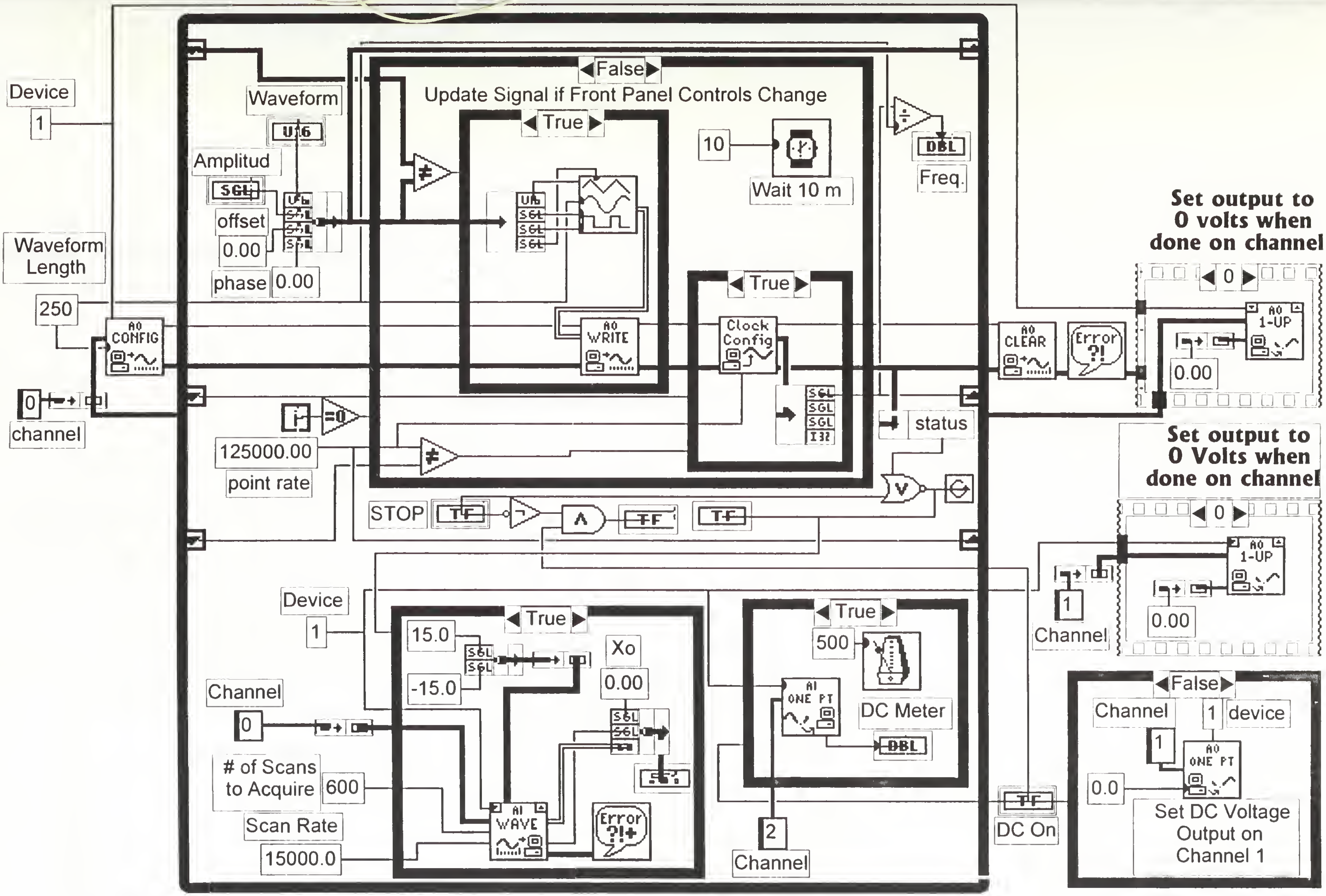
lock Diagram



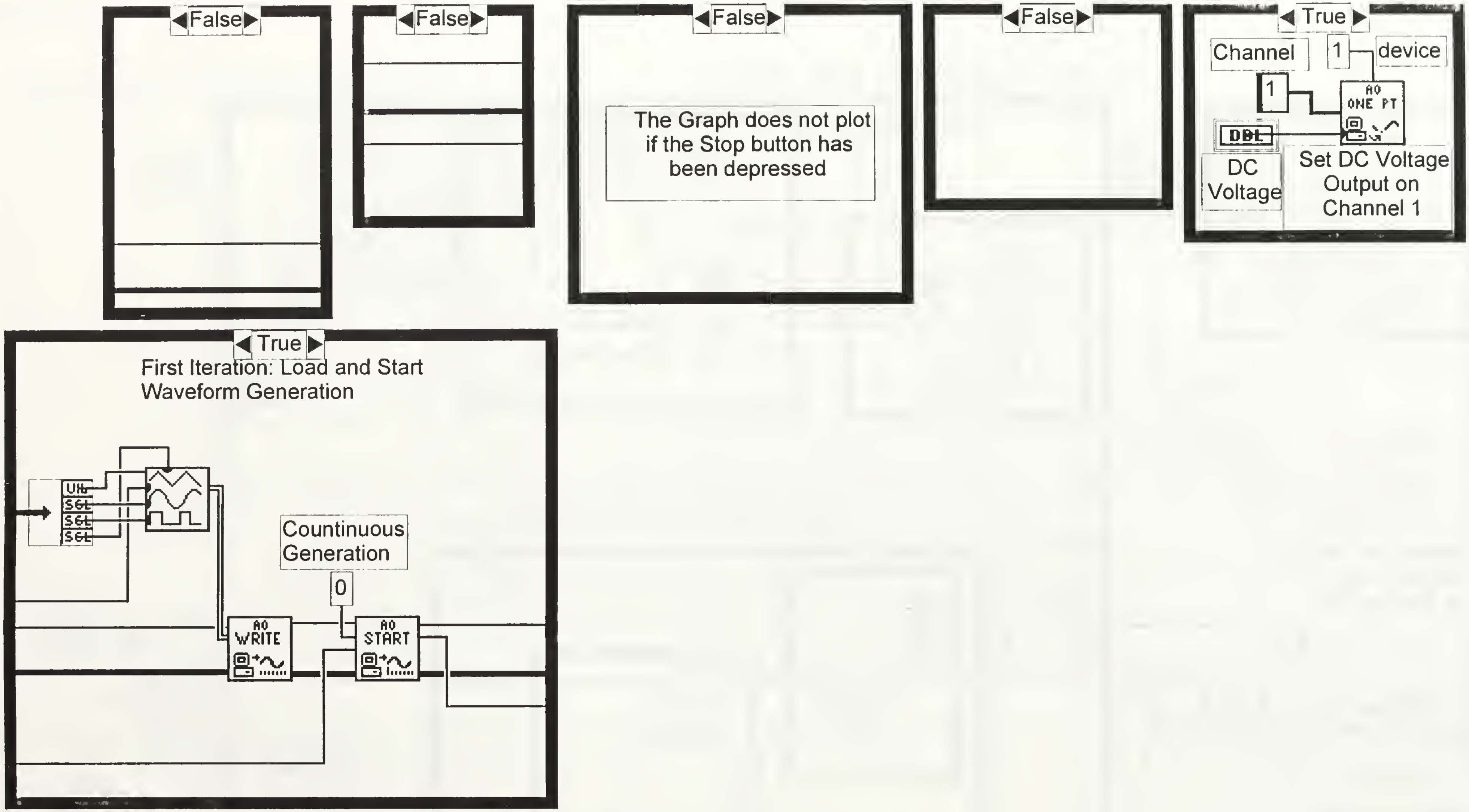

The Graph does not plot if the Stop button has been depressed
1
AO ONE PT
0.0
Set DC Voltage Output on Channel 1
True
First Iteration: Load and Start Waveform Generation
U16
SGL
SGL
SGL
Countinuous Generation
0
AO WRITE
AO START

Front Panel


TJS GRAPHICS' 94
STOP
DC On
DC Off
DC Voltage
0.00
EC 2200 Laboratory Experiment 7
Two Stage Transistor Amplifier
Naval Postgraduate School
Date
Name
DC Meter
0.0 2.0 4.0 6.0 8.0 10.0
0.00
Waveform
Sine
Amplitude (Peak)
1.000
Frequency (Hz)
0.00
Pin Layout
VS Input Pin 20 (+)
VCC Input Pin 21(+)
Meter Measurements:
Outputs: Pin 3 (+)
DC Pin 7 (+)
GRDs:
Pins 1,2,4,8,23
10.500 10.000 9.500 9.000 8.500 8.000 7.500 7.000 6.500 6.000 5.500 5.000 4.500 4.000 3.500 3.000 2.500 2.000 1.500
0.000 0.001 0.002 0.003 0.004 0.005 0.006 0.007 0.008 0.009 0.010



Device
1
Waveform Length
250
channel
0
Waveform
Amplitud
offset
0.00
phase
0.00
125000.00
point rate
STOP
False
Update Signal if Front Panel Controls Change
True
10
Wait 10 m
True
Clock Config
Freq.
status
Set output to 0 volts when done on channel
0
0.00
Set output to 0 Volts when done on channel
0
0.00
Channel
1
Device
1
Channel
0
# of Scans to Acquire
600
Scan Rate
15000.0
True
15.0
-15.0
Xo
0.00
True
500
DC Meter
2
Channel
DC On
False
Channel
1
device
1
0.0
Set DC Voltage Output on Channel 1


False
False
False
The Graph does not plot if the Stop button has been depressed
False
True
Channel
1
device
1
AO ONE PT
DBL
DC Voltage
Set DC Voltage Output on Channel 1
True
First Iteration: Load and Start Waveform Generation
Countinuous Generation
0
AO WRITE
AO START

APPENDIX B - LABORATORY EXPERIMENTS

Appendix B contains each Laboratory used with Virtual Instruments. The experiments have remained the same from the original Electronics Engineering course with the exception of voltage and resistor values. Each experiment is allotted one laboratory period (3 hours) for completion.

The Laboratory's that use the curve tracer have not been included since those do not involve any Virtual Instruments and remain as first designed.

NAVAL POSTGRADUATE SCHOOL
Monterey, California

EC2200 Laboratory **Sherif Michae**

Experiment 2

POWER SUPPLY CHARACTERISTICS AND DESIGN

OBJECTIVE

In the first part of this experiment, we will study the output characteristics of a dual in-lin full-wave bridge rectifier constructed using four silicon diodes enclosed in an epoxy case We will also observe the effect of a capacitor filter, varying the load resistance, and th effects of converting the circuit into a "regulated" power supply by shunting a zener diod across the output terminals.

In the second part you will design, build, and test a capacitor filtered bridge rectifier t supply 5 volts, 60 Hz, at 1 mA of load current with a ripple of less than 1.0V p-p.

You will also be required to improve the regulation of your dc power supply design b adding a Zener diode regulator.

EQUIPMENT:

Computer station with LabVIEW for Windows
Diode bridge rectifier (VM18)
Resistors (as called for by design)
Capacitor (as called for by design)
4.3 volt Zener diode (1N5229)
Decade Resistance Box

Select LabVIEW From the Windows menu. Double click on the LabVIEW Icon. When th "Untitled 1" screen appears, choose **Open...** from the **File** menu. Open the **2200LAB.LLB** file Select and open **LAB2 Pwr Supply Char & Design.VI**. When the front panel appears, use th *Operating* tool (pointing finger) to select the sine Waveform by clicking on the up or dow arrows. Place the tool over the line on the Amplitude knob, click and hold left mouse button an "rotate" full CW to 10.0 volts. Change o'scope display y-axis to 5.0 volts maximum value b placing tool over current value, then clicking left mouse button once, delete the current value, an type in 5.0. Click once outside the display to accept value.

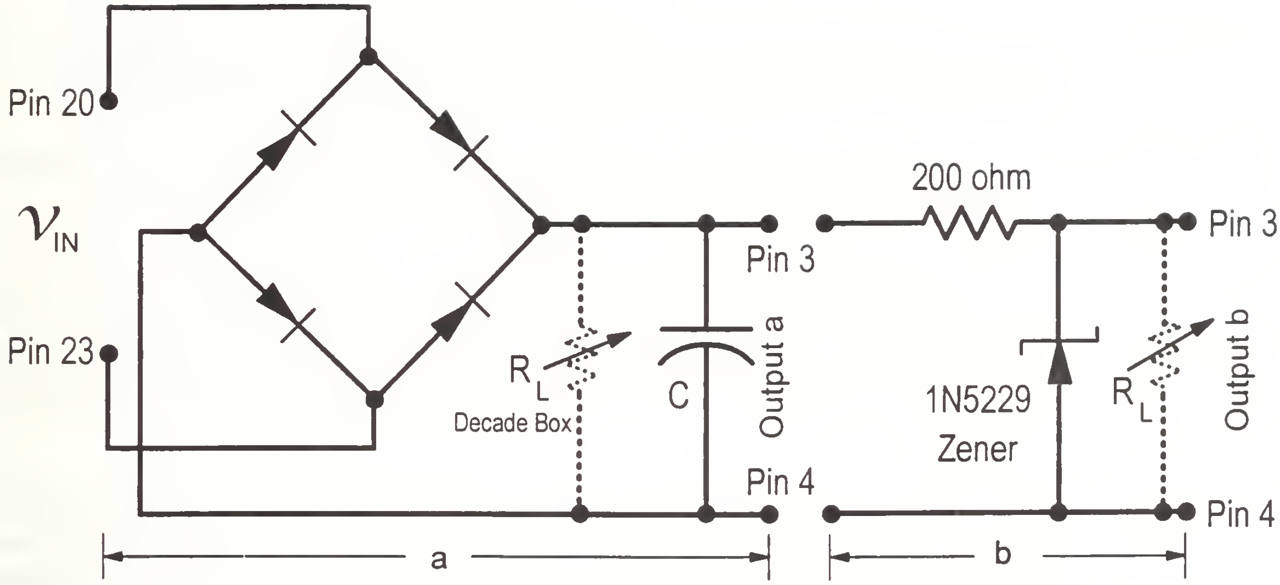


Fig. 1 Power Supply Circuit

PART I:

PROCEDURE

1.a. Connect the signal source to the bridge, pins 20 (+) and 23 (-). Do not ground the output of the source to any circuit ground.

b. Complete the circuit connections of Fig. 1 (section **a** only, with R_L set at 10K and without the capacitor). Connect pins 3 (+) and 4 (-) to obtain the output waveform. Click on the **Run** button to start the VI. Observe the output waveform and notice the DC output voltage on the meter. "Push" the **Stop** button to freeze the VI. (Compare the meter reading with that predictable from the output waveform.) Print the front panel by selecting **Print** from the **File** menu. When the print menu appears, select **All**, then **Print**, bit map printing is not required.

2.a. Connect a 10 µf capacitor in parallel with the load resistance as shown in Fig.1.a. **Run** the VI. Note the value of the peak-to-peak ripple voltage. **Stop** the VI. Observe the output rectified voltage on the meter. **Print** the front panel as above. (Explain any output changes produced by the addition of the capacitor. Compare the obtained ripple voltage with that predictable from theory.)

b. Repeat the above step with R_L set at 1K and then decrease down to 500Ω as you run the VI. (Explain all observed output changes as R_L is progressively decreased. How does the "regulation" of this circuit compare with that of the circuit with the unfiltered output?) **Stop** the VI.

3. Connect part **b** of Fig. 1.a to the rest of the circuit with the load resistance R_L moved t the output.

a. With R_L set at 10K. **Run** the VI. Observe and note the output waveform and DC mete voltage. (Compare all results with those obtained in Part 2a.).

b. Vary the circuit input voltage <u>downward</u> from 10 volts, the up/down arrows beside th digital amplitude display can fine tune voltage. Describe the <u>pattern</u> of the outpu waveform and voltage changes as v_{IN} is progressively decreased, noting any significar change(s) in this pattern. (Is the pattern predictable from theory?) **Stop** the VI whe completed.

c. Restore the circuit input amplitude to 10 volts. Observe the output characteristics with R set at 1K and then at 500Ω as you **Run** the VI. (Discuss the results and correlate an observed changes with theory as R_L is reduced. Describe and justify any differences in th "regulation" of this circuit compared with that of Part 2b.

<u>PART II:</u>

You are required to design a power supply that will provide the following:

1. 5 volts dc, 60 Hz with a ripple of less than 0.5V p-p.

2. Improve the regulation of your dc power supply by adding a Zener diode regulator.

<u>PROCEDURE:</u>

1. <u>Before coming to the lab</u>: Complete the design of your filtered rectifier on paper usin standard component values. Draw your circuit, labeling all pertinent values.

2. Build and test your power supply circuit following the preceding problem for VI setu **Run** the VI to obtain your waveforms. Ensure you **Stop** the VI before adding or removin any components. Take data, using pin 3 as pos (+) and pin 4 as neg (-), that will enabl you to find (directly or indirectly) the following: V_{dc}, V_p, V_r, I_L, and % regulation.

3.a. On semilog paper plot V_{dc} vs. R_L for values of R_L ranging between 500 ohms and 100 or larger. Explain the results.

b. On linear paper plot V_{dc} vs. V_p for various values of V_p with R_L = 5K. (You may **Run** th VI while increasing or decreasing V_p using the Amplitude knob.) Explain the results.

4. Improve your regulation by adding a 4.3 volt Zener diode (1N5229) and a resistor to your original dc power supply design. (You will want to increase V_p as well.)

Repeat step 3 noting the improved regulation. Draw your new circuit, labeling all pertinent values. Explain why the results of steps 3 and 4 are different.

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Experiment 3

DIODE CIRCUITS AND APPLICATIONS

OBJECTIVE

In this experiment, you will study the use of diodes as switching elements in the followin circuit applications: clipping, clamping, voltage doubling and gating. You will observe th input and output waveforms versus time and obtain transfer plots of the output versus th input voltage of the circuits.

EQUIPMENT:

Computer with LabVIEW for Windows and Connector Block
HP 721A Power Supply
Wavetek 142 Signal Generator
Resistors (different values)
Capacitors: 0.1 μF & 100 μF (2)
2 - 1N483B Diodes

Select LabVIEW From the Windows menu. Double click on the LabVIEW Icon. When th "Untitled 1" screen appears, choose **Open...** from the **File** menu. Open the **2200LAB.LLB** file Select and open **LAB3 Diode Circuits & Applications.VI**. When the front panel appears, use th *Operating* tool (pointing finger) to select 10.0 volts by clicking on the Amplitude (peak) up arrow Ensure the sine Waveform is selected.

PROCEDURE

A. Clipping Application:

1. Build the first circuit to be studied shown in Fig. 1. It is a basic rectifier circuit wherei a finite dc output component is obtained by halfwave clipping of a sinusoidal input voltage.

a. Connect the input voltage to the circuit, pins 20 (+), 23 (-). Use pin 3 (+) and pin 4 (- to observe input signals, and pin 5 (+) and pin 6 (-) for the outputs. Connect pins 1 an 2 to the other negative (-) pins for the entire experiment.

b. Apply the VI voltage to the diode circuit by clicking on the **Run** button. Observe the inpu and output voltages versus time on large o'scope screen. Does the half-wave clipping leve

deviate noticeably from zero? Stop the VI by clicking on the **Stop** button. Explain any deviation. What is the average or dc value of this half-wave rectified output?

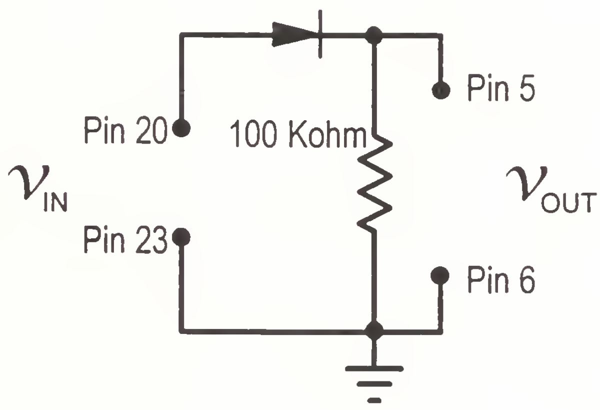

Figure 1 - Basic Rectifier

c. Observe the plot of the transfer character of the circuit, i.e., a plot of V_o versus V_i , in the lower left corner by turning **ON** the Transfer Characteristic switch and then **Run** the VI. **Stop** the VI. Change small o'scope display y-axis to 10.0 volts maximum value by placing *Operating* tool over current value, then clicking left mouse button once, delete the current value, and type in 10.0. Click once outside the display to accept value. Do the same for the x-axis maximum value using 12.0 as the new number. Relate the clipping action observed in Part b with the pattern of the transfer characteristic. Print the front panel by selecting **Print** from the **File** menu. When the print menu appears, select **All**, then **Print**, bit map printing is <u>not</u> required.

2. Set up the clipping circuit shown in Fig. 2 using a 10 volt peak V_i and a V_R of 3 volts. Set V_R by clicking on the up arrow of the DC voltage box until 3.0 is obtained. Connect the DC voltage by using pin 21 to the diode. Turn the DC power on by clicking above the DC switch. **Run** the VI. Observe the V_o waveform and the transfer characteristic. **Stop** the VI. Change o'scope display to obtain full transfer characteristic, (5.0, -12.0 for x- and y-axis). **Print** the front panel as in 1.c above. Reverse the polarity of V_R by clicking on DC voltage down arrow until -3.0 is reached. **Run** the VI and repeat these observations. Correlate the results with theory.

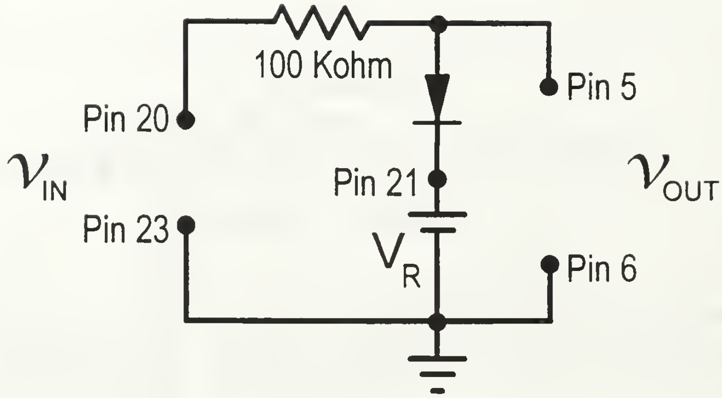

Figure 2 - Clipping Circuit

3. Change the DC voltage to +3.0. Modify the circuit of Fig. 2 by paralleling the diode - V_R string with a second diode in series with a dc source provided by the HP 721A and using the (+) and (-) outputs, ensure the HP 721A METER RANGE is set on 10 VDC. Design this circuit to provide a symmetrically clipped output waveform with maximum and minimum values of +3 and -3 volts, respectively. **Run** the VI and observe the waveform, adjusting both HP 721A and the DC Voltage as required. **Stop** the VI when proper output is obtained. Draw your circuit and **Print** the front panel output waveforms. Compare the average dc output level of this circuit with that obtained with the circuit of Part 1.

4. Restructure the clipping circuit to provide V_o maximum of +5 volts and a minimum of +2 volts. **Print** your results and draw your circuit.

B. Clamping Applications:

Fig. 3 shows a basic clamping circuit.

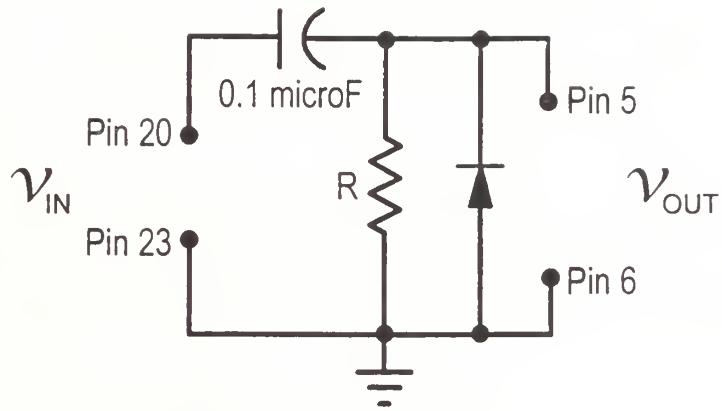

Figure 3 - Clamping Circuit

5. Set up the circuit using a square wave input of 5 V_{pp} at a frequency of 500 Hz (frequency is automatically selected). Obtain the output waveforms using resistor values of 15kΩ and 150kΩ respectively. **Run** the VI. **Stop** the VI to **Print** the waveforms, then note the zero level of both printouts. Reverse the diode and with R = 150kΩ **Run** the VI, **Print** the output waveform. Explain the differences in output waveforms obtained with the different circuit arrangements.

6. Restructure the circuit of Fig. 3 to provide an essentially square wave output that is top-clamped at +2.5 volts. Draw your circuit design and **Print** the obtained output waveform.

C. Voltage Doubling Applications:

7. Build the circuit shown in Fig. 4, applying a 5 V_{pp} square wave input, pin 20 (+) and pin 23 (-). Observe and then **Print** the output at point a, then point b. How does this output compare with your prediction?

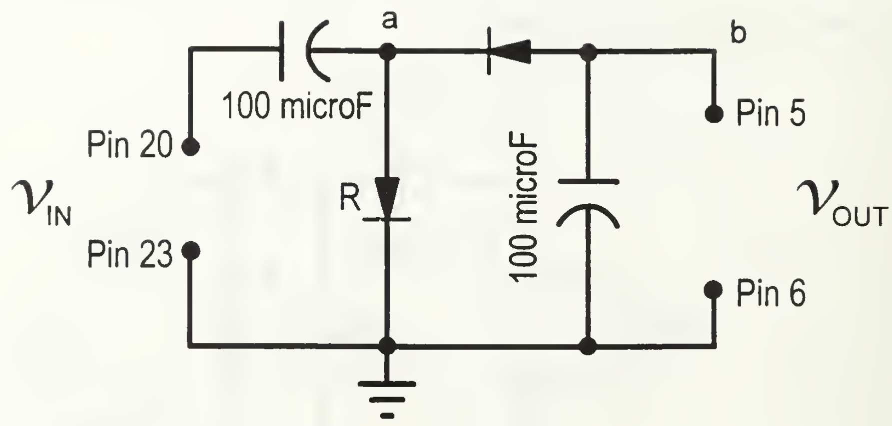

Figure 4 - Voltage Doubling Circuit

D. Gating Application:

8. Fig. 5 shows a gating circuit wherein a control voltage V_G determines the passage of a signal V_i from the input to output terminals. Let V_G be a square wave of 10 V_{pp} at a frequency of 500 Hz from the VI and V_i be equal to 5 sin $2\pi(10{,}000)t$ delivered from a second generator. (The second generator's output may be checked by connecting its output to pins 3 and 4, and connecting pins 5 and 6 together to avoid channel cross talk.) **Print** the input and output waveforms and explain the operation of the circuit.

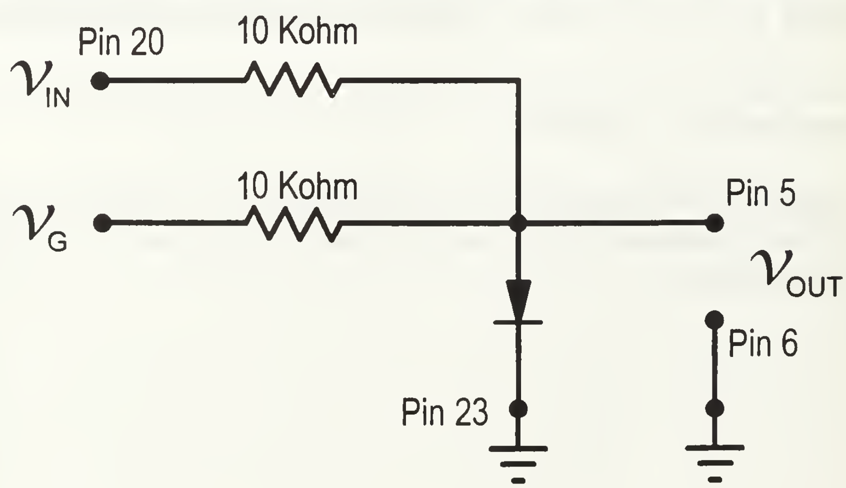

Figure 5 - Gating Circuit

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Monterey, California

EC2200 Laboratory **Sherif Michael**

Experiment 4

TRANSISTOR (BJT) CHARACTERISTICS

OBJECTIVE

In this experiment you will study the current-voltage relations of an NPN transistor in a common-emitter circuit configuration. Sets of input and output characteristics and the transfer characteristic will be obtained to provide information pertaining to both the static and dynamic operation of the device.

EQUIPMENT:

Computer Station with LabVIEW for Windows and Connector Block
Resistors (different values)
Transistor (2N3405 BJT)

Select LabVIEW From the Windows menu. Double click on the LabVIEW Icon. When the "Untitled 1" screen appears, choose **Open..** from the **File** menu. Open the **2200LAB.LLB** file. Select and open **LAB4 Transistor (BJT) Char.VI**.

PROCEDURE

1. Connect the circuit as shown in Figure 1, ensure all ground pins (1, 2, 4, 6, 8, 10, and 23) are connected together.

a. As indicated, R_B and R_C are to have a nominal value of 100kΩ and 10Ω, respectively. However, because they will be used to evaluate I_B and I_C a more precise value should be determined by ohmmeter measurement and the measured resistance should be used in the computations involving I_B and I_C.

2. Set V_{CC} at 5 volts. Click the DC switch to ON, then **Run** the VI. Obtain sets of data from the meters while varying V_{BB} in steps of 2 volts, from 0 to 10 volts, click DC switch OFF when completed. (The meter scales may need to be changed for needle movement.) Record the measured values of V_{CE} and V_{BE} and then compute the corresponding values of I_C and I_B derived from the relationships: $I_B = (V_{BB} - V_{BE})/R_B$ and $I_C = (V_{CC} - V_{CE})/R_C$

3. To obtain the transfer characteristic, use the data obtained to make an I_C versus I_B grapl Determine the dc current ratio of $\beta_{dc} = I_C/I_B$ in the vicinity of the static operating point using value of I_B = 15μA. At this point, estimate, from the slope of the graph drawn, the dynami current ratio, $\beta_{ac} = \Delta I_C/\Delta I_B$. Note any difference in the two β values. Estimate the β_{ac} value I_B approximately equal to 25 μA. Is there a measurable difference from that obtained at the lowe I_B level?

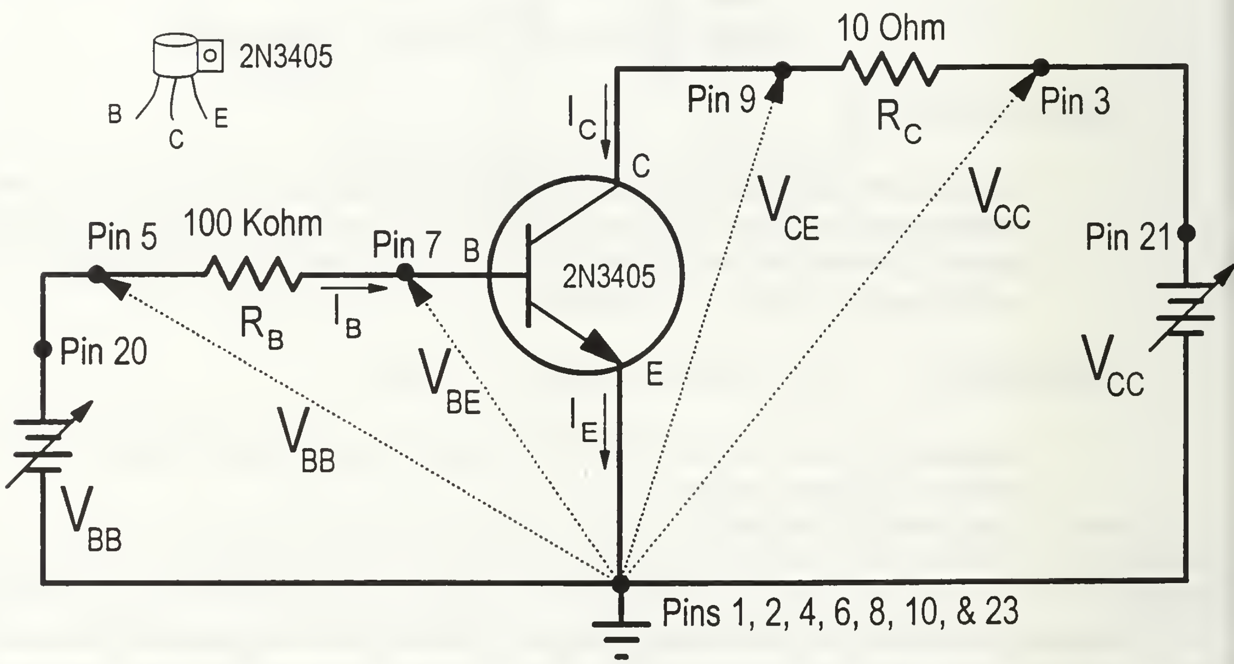

Figure 1 - BJT Circuit

4. To obtain an input current-voltage characteristic, use the data obtained in Part 2 to mak an I_B versus V_{BE} graph. How does the curve compare with a typical forward-biased dioc current-voltage characteristic? At the operating point I_B = 15μA, estimate the dynamic inpu resistance, $r_i = \Delta V_{BE}/\Delta I_B$. Does r_i vary significantly with change in the operating point to eithe a much lower or a much higher I_B level?

5. Shift V_{CC} to 10 volts and again take data for an input current-voltage characteristic. Plo this data on the same set of coordinate axis as in Part 4. Any noticeable shift in graph positio with change in V_{CC} is attributable to internal interaction from output to input. This effect can b specified as a dynamic reverse voltage transfer ratio, $\Delta V_{BE}/\Delta V_{CE}$. Determine this ratio at an I level of 15 μA.

6. Set V_{BB} = 10 volts and vary V_{CC} in steps of 2 volts, from 2 to 10 volts, to acquire the output current-voltage characteristic for a fixed value of base current. Record the corresponding values of V_{CE} and V_{CC} to determine I_C and then make an I_C versus V_{CC} graph. Label the graph with the fixed I_B value. What approximation is involved in assuming that this graph represents an output characteristic of the transistor, i.e., a plot of I_C versus V_{CE}?

7. Complete a 3-curve set of output characteristics by repeating the above procedure with V_{BB} equal to 7 volts and 4 volts respectively. Describe how this set of characteristics can be used to estimate the β_{ac} value of the transistor. Make this estimation around approximately the same operating point used in Part 3. Compare the results.

8. The slope of the output characteristics determines the dynamic output resistance of the transistor, specified as $r_o = \Delta V_{CE}/\Delta I_C$. Evaluate this parameter using the graph obtained in Part 6 in a range around the operating point V_{CC} = 6 volts.

Experiment 6

TRANSISTOR (BJT) AMPLIFIER DESIGN

OBJECTIVE

In this experiment you will design a BJT a Common Emitter Amplifier to specifications and test it for proper biasing in the active region, signal amplification characteristics and operational stability.

EQUIPMENT:

Computer Station with LabVIEW for Windows and Connector Block
2N3405 BJT
Resistors (different values as determined by design)
Capacitors (different values as shown in the circuit)

Select LabVIEW From the Windows menu. Double click on the LabVIEW Icon. When the "Untitled 1" screen appears, choose **Open...** from the **File** menu. Open the **2200LAB.LLB** file. Select and open **LAB6 Transistor (BJT) Amp Design.VI**

PROCEDURE

1. In the circuit of Figure 1, determine suitable resistance values for R_C, R_E, R_{B1}, R_{B2} to meet the following design specifications:

   a. $V_{CE(Q)} \approx$ 1/2 V_{CC}
   b. $I_{C(Q)} \approx$ 3 mA
   c. V_{CC} ☞ not to exceed 10 V
   d. $h_{FE}\, R_E$ $\approx 10\, R_B$ (R_B is the parallel combination of R_{B1} and R_{B2})
   e. $V_{BB} \geq$ $5V_{BE}$ (V_{BB} is the Thevinin voltage at the BJT base)
   f. R_C ☞ selected to maximize the small-signal voltage gain

2. Utilize the 2N3405 transistor for which you have previously obtained a photograph of output characteristics from a curve-tracer display, Lab 5. (Retake or plot an I_C - V_{CE} Characteristics if it is not already available.) Locate the specified operating point on the graph and estimate the h_{FE} value. Also obtain, for later use, a second 2N3405 transistor with an identified h_{FE} value that differs from your first by at least 100.

3. Set up the circuit with the selected components. Use ohmmeter measurements to determine specific resistance values. Set the DC Switch to 10 volts and turn the switch ON. **Run** the VI. Using pin 7 and the DC meter, measure $V_{CE(Q)}$ and determine $I_{C(Q)}$ then compare the measured values with those specified in the design. **Stop** the VI when complete.

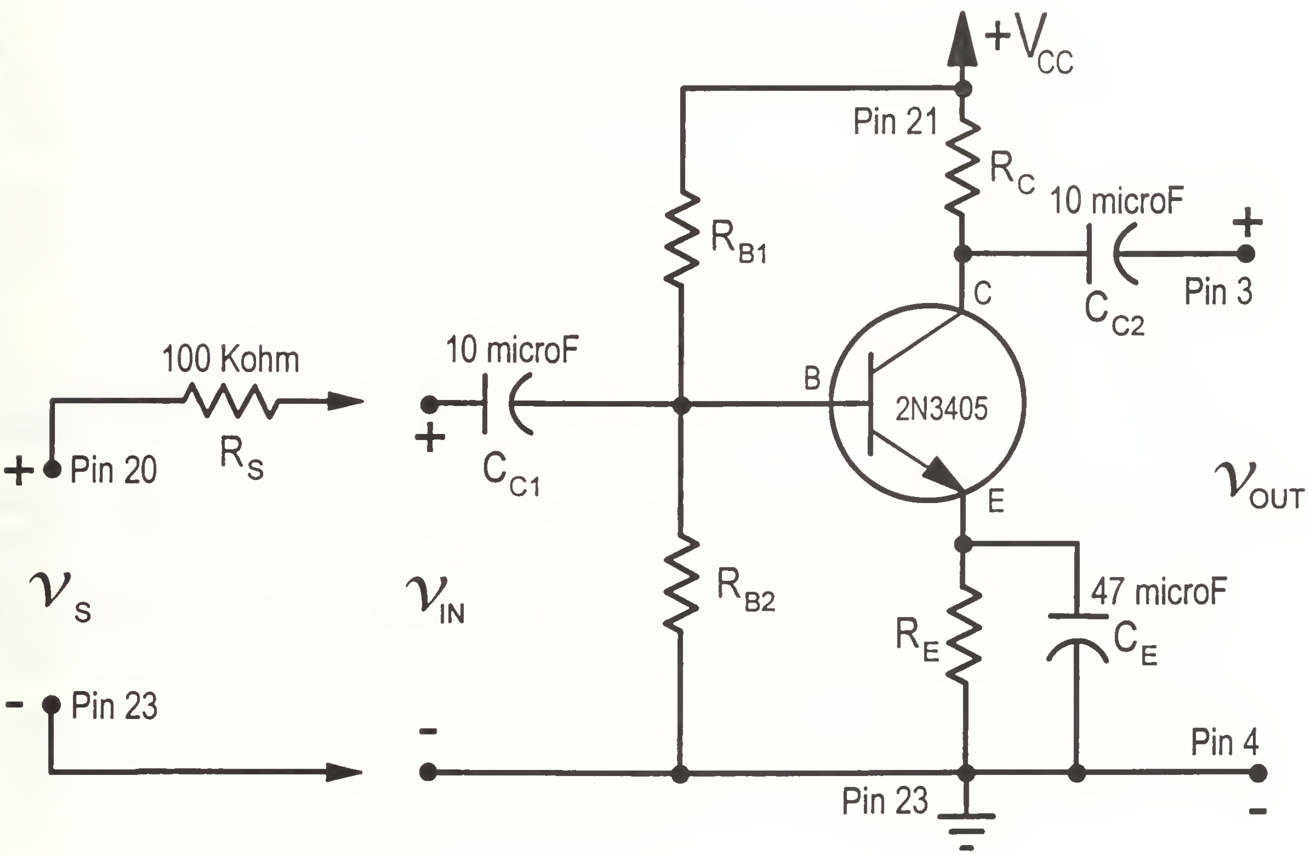

Figure 1 - BJT Amp

4. Substitute the second transistor in the circuit. **Run** the VI and measure $V_{CE(Q)}$ and $I_{C(Q)}$. **Stop** the VI. Compare the percent change in $I_{C(Q)}$ with the percent change in h_{FE} and comment on the relative stability of the bias of the circuit. Which of the design specifications given in Part 1 is primarily responsible for the degree of stability obtained?

5. Ground pin 7. Using your original transistor, apply a 500 Hz sinusoidal signal, from pin 20, to the circuit as shown in the diagram. **Run** the VI. Examine the output voltage waveform with the oscilloscope display and set the input signal amplitude at a sufficiently low level to provide a linear amplifier response.

6. With the VI running, use the o'scope display and measure V_s, V_i and V_o and then deriv the voltage ratios V_i/V_s, V_o/V_s and V_o/V_i. **Stop** the VI. From the voltage divider ratio V_i/V_s, determine a value for R_i, the transistor's input resistance, paralleling the R_B network Use this resistance value, together with your known value of h_{FE}, to calculate V_o/V_i Compare this calculated voltage gain with your measured value.

7. Repeat the measurements and calculations of Part 6 with the second transistor in the circui and make the corresponding comparison of calculated and measured data. Justify th relative effects of the h_{FE} changes on the measured gain V_o/V_s and V_o/V_i and then on th calculated R_i.

8. Remove the emitter-leg bypass capacitor, C_E, and restore your original transistor in th circuit. Repeat the measurements and calculations of Part 6. Justify the change in R_i an the resulting changes in the voltage gain ratio V_o/V_i affected by the removal of C_E.

9. Repeat the procedure of Part 8 with the second transistor in the circuit. Justify th observed effects of the h_{FE} change and compare them with those obtained in Part 7 wit the bypass capacitor in place. Comment on the gain stability of the two circuits.

10. Using your original circuit, increase the input signal until the output signal begins to shov distortion. Estimate the amplitude of this output voltage. Then further increase the inpu signal to the extent necessary to obtain a distortion effect on each peak of the output wave Now refer to your I_C - V_{CE} characteristics and, locating the quiescent point, correlate th experimental results with those predictable from the graph. Can a larger undistorted outpu be obtained with a different quiescent point?

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Experiment 7

TWO STAGE TRANSISTOR AMPLIFIER

OBJECTIVE

In this experiment you will study a two-stage RC-coupled linear amplifier with variable output-stage configurations. You will test it for proper biasing in the active region and signal amplification characteristics. You will also verify your lab results with a computer simulation of a proper transistor model using the SPICE program.

EQUIPMENT:

Computer Station with LabVIEW for Windows and Connector Block
2N3405 BJT (2)
Resistors (different values as specified)
Capacitors (different values as shown in the circuit)
Decade resistance box

Select LabVIEW From the Windows menu. Double click on the LabVIEW Icon. When the "Untitled 1" screen appears, choose **Open...** from the **File** menu. Open the **2200LAB.LLB** file. Select and open **LAB7 Two Stage Transistor Amp.VI**.

PROCEDURE

1. Set up the circuit shown in Fig. 1 using transistors with identified h_{FE} values. (If not previously determined, identify these values from an output-characteristics display on the curve tracer.) Determine and use a resistance value for R_{BX2} that will provide approximately the same quiescent operating point for both transistors. Initially include $C_{E(X)}$ in place as an emitter by-passing capacitor.

2. Adjust the DC voltage to 10 volts. Switch the DC voltage ON and let it remain on for the entire lab. **Run** the VI. Using pin 7, measure the dc voltages to ground at the base, emitter and collector of each transistor and compare these measured values with your respective calculated values to insure that both transistors are active. Read the measurement on the VI DC meter. **Stop** the VI when complete.

3. Apply a signal voltage (pin 20) at 500 Hz. **Run** the VI. Adjust the VI output to provide a voltage $V_{b(Y)}$ of 1 mV peak-to-peak. Using pin 3, examine the amplifier output waveform at terminal (A) to ensure that the amplifier response is linear. Measure the voltages $V_{b(X)}$ and $V_{o(A)}$ and derive the gain relations $V_{b(X)}/V_{b(Y)}$, $V_{o(A)}/V_{b(Y)}$ and $V_{o(A)}/V_{b(X)}$. **Stop** the VI when complete. Use these measured ratios and your known h_{FE} values to compute the dynamic input resistance of each transistor. Justify any significant resistance difference obtained between $r_{i(X)}$ and $r_{i(Y)}$.

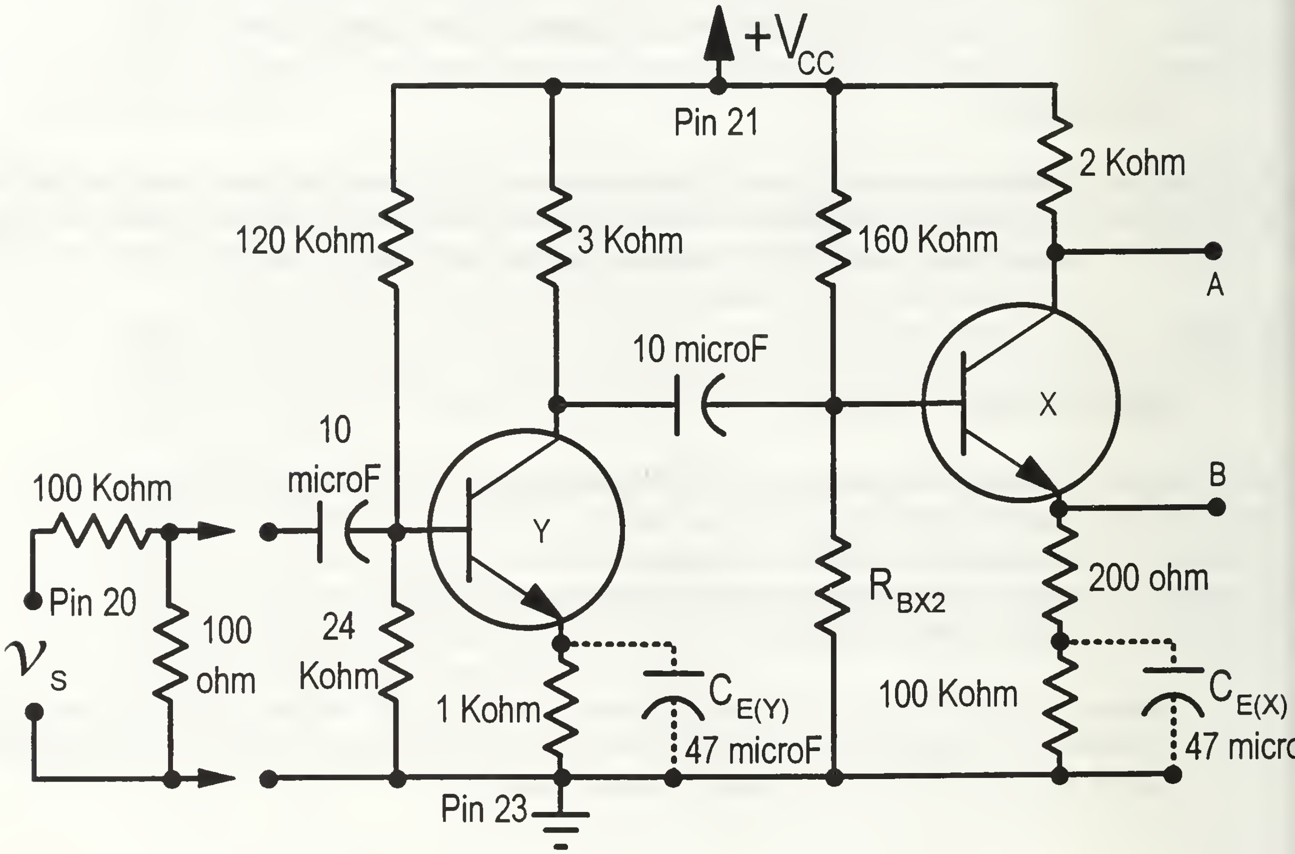

Figure 1 - Two Stage Amplifier

4. Remove capacitor $C_{E(X)}$ from your circuit. **Run** the VI and observe the waveforms $V_{o(A)}$ and $V_{o(B)}$ and note the phase relationships. **Stop** the VI when complete. **Print** the front panel waveforms. **Run** the VI once again. Using pin 3 as the probe with pin 4 grounded, measure the peak-to-peak voltages $V_{b(X)}$, $V_{o(A)}$ and $V_{o(B)}$ on the o'scope screen. **Stop** the VI when complete. Derive the gain relations: $V_{b(X)}/V_{b(Y)}$, $V_{o(A)}/V_{b(Y)}$, $V_{o(B)}/V_{b(Y)}$, $V_{o(A)}/V_{b(X)}$ and $V_{o(B)}/V_{b(X)}$. Use appropriate ratios to compute resistance values for $r_{i(X)}$ and $r_{i(Y)}$. Correlate with theory the relative amplitudes and phase of $V_{o(A)}$ and $V_{o(B)}$ and the various operational changes affected by the removal of $C_{E(X)}$.

5. With $C_{E(X)}$ remaining out of the circuit, determine the output resistance of the amplifier at terminals (A) and (B), respectively, by connecting the RC network shown in Figure 2 to the terminal under test. **Run** the VI for each terminal. Adjust the decade resistance box until the output voltage at the terminal is reduced to half the value it had before adding the shunting network. **Stop** the VI when complete. Justify any observed difference in the two resistance measurements. Comment on the operational significance in the use of either connection for driving a succeeding stage or circuit.

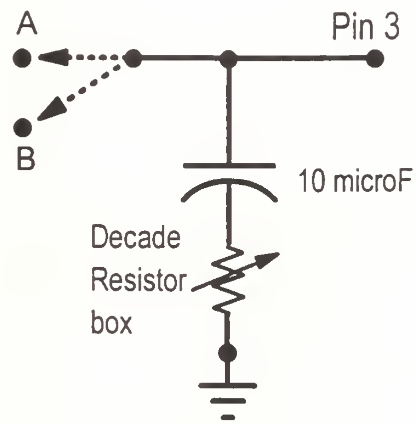

Figure 2 - RC Network

6. Using SPICE, verify the findings in 2, 3 and 4 utilizing a proper transistor model that has the same parameters as your devices used in your experiments. Turn-in the output of the program with your Lab report.

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